FERTILITY STUDIES WITH RADIOACTIVE AND NON-RADIOACTIVE SULFUR ON SOME GREY WOODED SOILS OF ALBERTA

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University of Alberta

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FERTILITY STUDIES
WITH RADIOACTIVE AND NON-RADIOACTIVE SULFUR
ON SOME GREY WOODED SOILS OF ALBERTA

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SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES
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DEPARTMENT OF SOILS

by

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FERTILITY STUDIES
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INTRODUCTION

Sulfur is an essential plant nutrient and green plants with their great synthetic power are the ultimate source of sulfur for all animals. It is an essential constituent of the amino acids cystine and methionine, two of the building stones of body proteins, and of the vitamins biotin and thiamin. Many other organic sulfur compounds have been isolated from plants but little is known of the significance of these compounds, either to the plants that synthesize them or to the animals that consume them. Since sulfur-containing amino acids are essential constituents of plant proteins a close relation must exist between sulfur and nitrogen metabolism. Further, the characteristic yellowing of plant leaves caused by sulfur deficiency suggests that sulfur may be indirectly involved in chlorophyll metabolism.

The fact that plants synthesize many organic sulfur compounds, several of them known to be essential to plant and animal nutrition, puts sulfur in a class with nitrogen and phosphorus and justifies an inquiry into its possible deficiency in agricultural soils.

The level of sulfur fertility of a soil is difficult to evaluate. Sulfur forms soluble compounds that are readily leached away and the atmosphere contains variable amounts of gaseous

sulfur compounds that are added to the soil by precipitation and by direct absorption. Investigations have shown that many of the grey wooded soils of Alberta require sulfur fertilization for the maintenance of high crop yields, particularly where legumes are concerned.

The grey wooded soil zone is sparsely populated and a very small proportion of the land is as yet under cultivation. Any agricultural expansion program in Alberta must be confined largely to this zone. Since these soils are low in natural fertility special attention must be given to their management and fertilization if satisfactory returns are to be obtained and maintained.

In order to investigate the fertilizer requirements of grey wooded soils experiments have been conducted by the Soils Department of the University of Alberta. These experiments are of two types: (1) those carried out on the Soils Department plots at Breton, and (2) co-operative experiments with farmers. These experiments have shown that large areas of sulfur-deficient grey wooded soil exist in Alberta. Large increases in yield have been obtained from the application of sulfate fertilizers to legume crops, but little, if any, beneficial effect on cereal crops has been noted. However, the application of sulfur fertilizers to legume crops has produced substantial yield increases in the subsequent cereal crops.

In order to obtain information regarding sulfur fertilizer uptake, experiments were begun in 1949 using radioactive sulfur as a fertilizer tracer. The results of the 1949 investigations

have been reported by Cormack (14).

It is the purpose of this thesis to report the results of the 1950, 1951 and 1952 investigations.

REVIEW OF LITERATURE

Bogdanoff, a Russian chemist, was the first to emphasize the importance of sulfur in soil fertility. In 1898 (4,5) he found the application of Na_2SO_4 to certain black soils of Russia greatly increased the yields of white mustard and of some other crops. This prompted him to determine the sulfur content of plant material by several methods. His analyses show that the ash analyses of Wolff in many cases gave only a small fraction of the actual sulfur present. Swanson and Latshaw (46) compare the results of Hart and Peterson (24) and of Wolff to show how erroneous the early method of ash analysis was. A few of the comparisons made are shown in Table I.

TABLE I
Sulfur content of common farm crops as determined by Hart and Peterson and Wolff

Crop	% S Hart and Peterson	% S Wolff
Alfalfa hay	0.29	0.17
Red clover	0.16	0.09
Oat grain	0.19	0.002
Oat straw	0.20	0.09
Wheat grain	0.17	0.003
Wheat straw	0.12	0.05

The low sulfur content obtained by the Wolff ashing method led the early workers in soil fertility to assign to sulfur a role of minor importance in soil fertility practices. Another reason why the possibility of sulfur as a limiting factor in crop production was not earlier recognized was the incidental application of sulfur to soils in connection with the use of nitrogen, phosphorus and potassium fertilizers. Ammonium sulfate, potassium sulfate, superphosphate and ammonium phosphate are well known examples of sulfur carriers. Sauchelli (42) reports that one-third of the annual total production of H_2SO_4 in the United States, about 3.5 million tons (100% basis), is used in the manufacture of commercial fertilizers. Mehring and Bennett (30) report that three-fourths of the tonnage of all fertilizers consumed in the United States in the year ending June 30, 1948, contained more SO_3 than the combined tonnages of N, P_2O_4 and K_2O. They conclude that sulfur would probably be needed in many other areas if high analysis fertilizers comparatively free of sulfur were substituted for those currently in use.

Today sulfur-deficient soils are recognized (1,6,12,13, 15,16,35,55) as being of common occurrence on the North American continent and elsewhere. Alway, Conrad _et al._, Hart and Peterson, Newton, Powers, Reimer and Tarter (1,13,24,34,38,39) have found increases in the yields of legumes when sulfur fertilizers were applied to soils deficient in sulfur. Crocker (15) reports that the most striking increases were those found in certain soils of Oregon where yields of alfalfa have been increased by as much as 500 to 1000% through the use of sulfur fertilizers. Bollen (10)

working with five soil types in Iowa found that the application of gypsum increased the yield of oats and clover in a number of cases and increased the yield of alfalfa in all cases. Younge (55) has found ten soil types of Arkansas to be sulfur-deficient with respect to cotton. Alway et al. (2) have found a belt through the middle of the northern half of Minnesota where available soil sulfur is deficient for maximum production of alfalfa, sweet, alsike and red clover. A number of other sulfur deficiencies in the United States and foreign countries might be cited. Bledsoe and Blazer (7) state sulfur-deficient soils have been reported by 15 states in America and by three provinces in Canada. In general, the sulfur-deficient areas in the United States are confined to the Pacific, Atlantic and Gulf Coast states and in these areas to upland and alluvial soils (7, 12, 13, 38, 55).

Until quite recently the soils of Alberta were thought to be fairly well supplied with sulfur. Wyatt and Doughty (54) in 1928 reported Alberta soils well supplied with sulfur as compared to American soils with reported sulfur deficiencies. It is now recognized (14, 34, 35, 36, 53) that extensive areas of sulfur deficiency exist in Alberta but that these areas are confined largely to the grey wooded soil zone.

The sulfur content of surface soils is generally associated with the organic matter content (16, 18, 52). Wyatt and Doughty (op. cit.) found that the sulfur content of soils varies inversely as the degree of leaching and that the zone of sulfate concentration is usually slightly deeper than the lime layer.

It has been shown (16, 36, 54) that the sulfur content of the grey wooded soil of Alberta is less than that of the brown and black soils, which contain on the average about three times as much sulfur as the grey wooded soils. Dean (16) reports the following average percentages of sulfur in soils of the prairie provinces.

Zone	% S
Black	0.08
Brown	0.046
Grey wooded	0.02

The sulfur content of non-alkali soils is usually less than the phosphorus content (11, 31, 45, 54). Lipman and Conybeare (28) report that United States soils contain about 60% as much sulfur as phosphorus. The lower percentage of sulfur in the soil as compared to phosphorus takes on added significance when one realizes the sulfur requirements of many plants are nearly as high as the phosphorus requirements. Brown and Kellog (11), Hart and Peterson (op. cit.) and Shedd (45) have shown that many cultivated plants contain more sulfur than phosphorus. The data abstracted from Morrison (32) and reported in Table II give the percentages of sulfur and phosphorus in some of the common cereal, forage and other crops.

TABLE II
Sulfur content of common farm crops

Crop	% P	% S
Alfalfa	0.24	0.32
Red clover	0.19	0.14
Sweet clover	0.23	0.41
Wheat grain	0.39	0.20
" straw	0.07	0.16
Oat grain	0.34	0.21
" straw	0.10	0.22
Beet pulp	0.08	0.20
Potatoes	0.05	0.02
Cabbage (green)	0.03	0.11

Mehring and Bennett (op. cit.) report the ratio of the N, P_2O_5, K_2O, and SO_3 contents of all crops harvested in the United States as 1:0.4:0.6:0.3 respectively.

Alway et al. (2) have made an extensive study of the addition of sulfur from the atmosphere through precipitation and direct absorption by soils and plants. They point out that early workers using galvanized collection vessels obtained high values, due to the solution of sulfur from the galvanized surface and the absorption by the water surface of sulfur dioxide from the atmosphere. The error due to the latter is particularly large near industrial or population centers where the sulfur dioxide content of the atmosphere is high. Alway (op. cit.) cites the work of Kossowitch, a Russian agronomist, as being the most reliable early information concerning the sulfur content of rainwater. Near St. Petersburg the annual amount of sulfur found was 28 lb.

per acre; 19 miles south only 6.1 lb. were found. At four rural stations low annual amounts of 3.8, 2.6, 3.2 and 2.7 lb. per acre were found. These amounts compare with those found by Alway for rural regions of Minnesota. More recently Volk *et al.* (49) using specially designed collection vessels, investigated the sulfur content of precipitation at 12 locations in Alabama. The annual sulfur precipitation in the rural areas ranged from 7.2 lb. per acre at Kinston to 15.5 lb. at Belle Mina, while at Birmingham 76.8 lb. of sulfur were brought down. They conclude that sulfur precipitation in the rural areas is insufficient to replace the sulfur used by crops and leached away annually. In general, the sulfur content of rainfall varies directly as the sulfur dioxide content of the atmosphere, becoming less significant the greater the distance from industrial and population centers.

Alway *et al.* (op. cit.) in their studies of the absorption of sulfur dioxide by the soil from the atmosphere used specially prepared lead peroxide surfaces. Their studies of sulfur dioxide absorption by the soil led to the realization that direct absorption by the soil may be a significant source of sulfur. Where the sulfur dioxide content of the atmosphere is high as in the center of Minneapolis, the amount of sulfur absorbed by the lead peroxide surface was several times as high as the amount brought down in precipitation, amounting to 532 lb. per acre annually. At Bemidji in northern Minnesota the annual absorption was 3.6 lb. per acre. The Soils Department of the University of Alberta working in conjunction with Alway (op. cit.)

found an annual absorption of 3.3 lb. per acre at Edmonton and 0.8 lb. per acre at Breton (unpublished data, Soils Department, University of Alberta). The amount of sulfur dioxide absorbed by a soil depends primarily on its physical condition, texture and extent of aeration. Alway et al. (op. cit.) found soils of medium texture absorbed approximately 22% as much sulfur dioxide as was absorbed by the lead peroxide surfaces used in their investigation.

The direct absorption of sulfur dioxide from the atmosphere by plants has long been postulated. Fried (20) using radioactive sulfur has definitely established that plants can take in sulfur dioxide through the leaves and convert it into organic sulfur compounds. In the earlier investigations the growing medium had not been isolated from the sulfur-containing atmosphere, leaving the possibility that the sulfur dioxide may have been absorbed by the growing medium, oxidized to sulfate and taken up by the plant in this form. Thomas and Hill (48) working with an atmosphere containing about 0.44 p.p.m. (approximately 8 times the normal concentration) found approximately 46% of the sulfur dioxide was absorbed by alfalfa leaves without injury to the plant and that 3.02 gm. of sulfur were absorbed for every 3035 gm. of carbon assimilated. Alway et al. (op. cit.) basing their calculations on the work of Thomas and Hill suggest that not more than 0.75 lb. of sulfur per acre should be expected annually from the direct absorption of sulfur dioxide by alfalfa. It has been shown by Thomas et al. (47) that in general plants growing near industrial and population centers have a higher

average sulfur content than plants growing in rural areas. They report that Katz and McCallum were able to correlate the sulfur content of the leaves of trees and shrubs with the distance down the narrow Columbia River valley from the Trail smelter, the sulfur content becoming less as the distance increased. The sulfur content gradient would be due to increased soil absorption, leaf absorption and an increase in the sulfur content of the precipitation in the vicinity of the Trail smelter. It may be concluded that where sulfur is the limiting factor in crop production, the sulfur in precipitation and to a lesser extent the sulfur dioxide absorbed by the soil and by the plant may be considered of some significance in supplying the sulfur deficiency.

Sulfur in the form of sulfates is readily leached from the soil. Lyon and Bizzell (29) working at Cornell report that the loss of sulfur due to drainage is from three to six times that removed by crops and three times that added in rainfall. Little data regarding sulfur losses due to soil erosion are available. Most investigators agree that where little or no conservation practices are employed the sulfur loss is at least equal to or greater than that removed by crops.

Dymond, Huges and Jupe (17) working at a county farm at Chelmsford, England, were the first to draw up a balance sheet for sulfur as a crop nutrient. From this study the authors drew the following conclusion: "There is not sufficient sulphuric acid in the soil or supplied by rain for heavy yielding crops rich in albuminoid, either for the production of greatest yield

or the highest feeding value and for such crops a sulphate should be included in the artificial manure. For cereal crops and for permanent pasture the soil and rain provide all the sulphuric acid necessary." Brown and Kellog (op. cit.), Hart and Peterson (op. cit.) and Shedd (op. cit.) in drawing up balance sheets for the soils of Iowa, Wisconsin, and Kentucky respectively, arrived at a similar conclusion. More recently Lipman and Conybeare (28) drew up a balance sheet of the principal plant nutrients for the soils of the United States including crop land, farm pastures, and pastures not on farms, a total of 1,445,390,414 acres based on the 1930 census. Their balance sheet with respect to phosphorus and sulfur may be briefly summarized as shown in Table III. Nearly one-fourth of the sulfur addition is by irrigation, which is limited to aridic lands usually rich in sulfates; if this addition be neglected then the net annual loss of sulfur is eight instead of five pounds per acre. The summary indicates that the amount of sulfur added in rainfall is not sufficient to make good that lost by leaching. This would suggest that any system of soil fertility management should give some consideration to sulfur if high productivity is to be maintained, particularly where legume crops are concerned.

TABLE III
Annual balance sheet
of nitrogen, phosphorus and sulfur
for cultivated soils of the United States, 1930

	Lb./acre N	 P	 S
Additions:			
Fertilizers	0.4	0.5	1.0
Animal manures and bedding	3.5	1.5	0.5
Green manures	0.08	0.01	0.01
Rainfall	4.6	Nil	7.9
Irrigation	0.04	Nil	3.1
Seeds	0.2	0.04	0.02
Roots and unharvested portions of plants	1.5	0.2	0.2
Nitrogen fixation	13.5	Nil	Nil
Total	23.8	2.3	12.7
Losses:			
Harvested crops	6.3	1.0	0.7
Animals and animal products	1.0	0.2	0.04
Grazing	11.4	1.8	1.3
Crop exports	14.9	2.7	1.2
Animal exports	2.2	0.2	0.1
Erosion	6.9	2.9	1.7
Leaching	6.9	Nil	12.8
Total	49.6	8.8	17.8
Net annual loss	26.8	6.5	5.1

The fate of fertilizers after addition to the soil has long been a basic problem of agronomy. In the past it has been impossible to determine what proportion of the sulfur absorbed by the plant was derived from the fertilizer. By applying radioactive tracer technique to studies involving the utilization of sulfur fertilizers, the relative amounts of soil sulfur and applied sulfur absorbed by the crop can be determined. The

application of tracer techniques to biological problems does not require a detailed knowledge of the physical background of atomic and nuclear physics. Radioactive sulfur, S^{35}, and ordinary sulfur, S^{32}, are assumed to be absorbed alike by the plant and to perform the same functions in the plant. Both forms have the same chemical properties, but they differ in one important respect; the radioactive S^{35} atoms disintegrate releasing beta particles which are easily detected by a Geiger-Müller counter. The purpose of adding radioactive sulfur to sulfur fertilizer is to provide a "tag" for determining how much of the sulfur absorbed by a crop comes from the added fertilizer. A fertilizer containing S^{35} will have, at any particular time, a definite radioactivity. Thus, if the sulfur separated from the plants is only one-tenth as active as that in the fertilizer then only one-tenth of the sulfur came from the fertilizer.

The unit of radioactivity is the curie and is now accepted as meaning the amount of radioactive isotope required to give 3.7×10^{10} disintegrating nuclei per second. The quantities used are generally so small that amounts are expressed as millicuries (10^{-3} curies) or as microcuries (10^{-6} curies). The half-life is the time required for one-half of the initial quantity of the radioactive substance to disintegrate. The long half-life (87.1 days) of the isotope S^{35} makes it particularly suitable for studies of the type reported in this thesis where the experimental procedure involves a considerable period of time.

In the use of radioactive isotopes in fertilization studies the possibility of radiation injury must be considered

and very little if any work has been done with S^{35} in this regard. Radiation effects concerning P^{32} have been investigated by a number of workers (8, 9, 40, 41), with inconsistent results. Russell and Martin (41) working with barley growing in a nutrient solution, suggest the maximum non-injurious level is about 10 microcuries of P^{32} per litre of solution used. Blume, Hagen, and Mackie (8) in a similar investigation, report the lowest level at which radiation damage occurred under their conditions corresponded to 5.6 millicuries of P^{32} per gram of P_2O_5, a level higher than that usually employed in plant nutrition studies. Recently Blume, using solutions of KH_2PO_4 containing up to 12.5 millicuries of P^{32} per gram of P^{31}, reported that though differences in yield, phosphorus content and percentage fertilizer phosphorus were sometimes statistically significant, the differences were too small to appreciably affect the data gained by the use of the isotope.

While results from studies with P^{32} may give some indication of the levels at which radiation injury can be expected, they are not applicable to problems involving other isotopes since the half-life, kind and energy of the radiation, percentage uptake, distribution within the plant and length of exposure are all factors which will affect the amount of injury inflicted. It is generally accepted that the low levels of radiation employed in tracer work will have insignificant radiation effects. In the investigation reported in this thesis an attempt was made to determine if the low levels of activity used were having any significant effect with respect to yield and fertilizer uptake.

OUTLINE OF INVESTIGATION

The work reported in this thesis was carried out during the years 1950, 1951 and 1952. It is a continuation of the sulfur fertility investigation of grey wooded soils using S^{35} as a fertilizer tracer begun by the Soils Department in 1949. The results of the 1949 experiments were reported by Cormack (op. cit.) in his thesis.

Experiments were conducted on legumes and grains at the Breton experimental plots (grey wooded soil), at the Soils Farm experimental plots (black soil) and on farm fields in widely separated areas of grey wooded soil. The experiments conducted can be grouped as follows:

A. Levels Experiment

This experiment was conducted in 1950 on a field of Montcalm barley immediately south of and adjacent to the Breton experimental plots. S^{35} was applied at four levels to determine the effect of radiation at the different levels. The experiment consisted of three blocks, each block being comprised of four treatments replicated 10 times. The treatments were as follows:

Treatment	Rate of application per sq. yd.	Level of S^{35} mc./gm. Na_2SO_4
Level 1	0 mc. S^{35} + 9.38 gm. Na_2SO_4	0
Level 2	0.04 " " + " " "	0.0043
Level 3	0.1 " " + " " "	0.0107
Level 4	0.3 " " + " " "	0.0320

9.38 gm./sq. yd. = 100 lb./ac.

Each treated area consisted of one square yard, with three-foot spacings between treatments. The blocks were sampled

at different times during the growing season. Yield samples consisting of the inner four square feet were taken and subjected to statistical analysis. The percentage sulfur and fertilizer sulfur in the crop were determined for blocks II and III.

B. Sulfur Uptake Experiments

These experiments were conducted during 1950, 1951 and 1952 on legumes and grains at the Breton and Soils Farm experimental plots, and in 1951 and 1952 on farm fields in widely separated areas of grey wooded soil. These experiments were designed to obtain information concerning the following: (1) the uptake of fertilizer sulfur by cereal and legume plants, (2) the most suitable rate of sulfate fertilization for legumes grown on grey wooded soil, and (3) the effect of sulfate fertilization on the composition of the plants concerned.

In 1950 at the Breton and Soils Farm experimental plots individual square yard plots of grain and legumes were treated with Na_2S*O_4 containing 0.0107 mc. of S^{35} per gram of Na_2SO_4. At Breton on the legumes on plot four, series B and C (see p. 22) four treatments replicated six times were applied as follows:

Treatment 1 - check
" 2 - Na_2S*O_4 @ 30 lb./ac.
" 3 - " @ 100 " "
" 4 - " @ 300 " "

On the grains and the other legumes only treatments 1 and 3 were applied, each treatment being replicated six times at Breton and three times at the Soils Farm. In 1951 and 1952 solid blocks were treated with Na_2S*O_4 at a rate supplying 20 lb. of

sulfur per acre and containing 0.0107 mc. of S^{35} per gram of Na_2SO_4. These blocks were 5 feet by 17 feet at Breton and 5 feet by 11 feet at the Soils Farm, allowing 5 and 3 square yard samples to be taken respectively. Check samples were taken five feet distant from and parallel to the treated blocks. The grain experiments on farm fields, using the same treatment, were laid out in two blocks 5 feet by 11 feet allowing three square yard samples to be taken from each. Check samples were taken as at Breton and the Soils Farm.

The legume experiments on farm fields consisted of a 4 x 4 Latin square, each treated area being five feet square with five-foot spacings between treatments. $Na_2S{*}O_4$ containing 0.0107 mc. of S^{35} per gram of Na_2SO_4 was applied as follows:

Treatment 1 - check
" 2 - $Na_2S{*}O_4$ supplying S @ 10 lb./ac.
" 3 - " " " @ 20 " "
" 4 - " " " @ 50 " "

In connection with the sulfur uptake experiments, "translocation" samples were taken. These were samples taken at different distances from the treated areas. By determining the percentage of fertilizer sulfur present the extent of lateral movement of $Na_2S{*}O_4$ could be measured.

C. Yield Experiments With Different Sulfur Fertilizers

These experiments were conducted in 1951 and 1952 on farm fields of legumes and grains in conjunction with the sulfur uptake experiments, to determine the effect of different sulfur fertilizers on yield and on crop composition. Flowers of sulfur and different sulfur-containing fertilizers supplying sulfur at

20 lb. per acre were applied in the form of a randomized block. In the experiments conducted in 1951, each plot was 40 feet square and the treatments, each replicated four times, were as follows:

Treatment	Fertilizer	Rate lb./ac.
1	Check	
2	Check	
3	Flowers of sulfur	10
4	" " "	20
5	" " "	50
6	$CaSO_4$	111
7	$(NH_4)_2SO_4$	80
8	Na_2SO_4	91
9	16-20-0	143
10	Na_2SO_4	68
	+ trace mixture	50

The above rates, except flowers of sulfur at 10 and 50, supply sulfur at 20 lb. per acre. The trace mixture consisted of the following:

MnO_2 - 30 parts
$CuSO_4$ - 15 "
$ZnSO_4$ - 15 "
Borax - 15 "
$Na_2MoO_4 \cdot 2H_2O$ - 1 "
$Co_2(SO_4)_3$ - 1 "

In the 1952 experiments the treatments supplying flowers of sulfur at 10 and 50 lb. per acre were omitted, all treatments

were replicated six instead of four times, and the plot size was reduced to 20 feet square.

D. Fall versus Spring Fertilizer Application Experiments

During the fall of 1950 fall applications of sulfur fertilizers were made on two legume fields; these were followed in 1951 by a spring application of the same fertilizers. The fall and spring treatments were randomized in the same block, each plot being 40 feet square and each treatment being replicated 4 times. The treatments were the same as those in the 1951 yield experiments on legumes and grains.

E. Feeding Depth Experiments

During 1952 feeding depth experiments were placed on two legume fields in conjunction with the sulfur uptake and yield experiments. Active and inactive Na_2SO_4 was applied at the rate of 20 lb. per acre at different depths to determine the extent of removal of sulfur from the lower soil horizons. The inactive Na_2SO_4 was included to determine if the presence of sulfur in a particular soil horizon would influence the feeding depth of the plant. The treatments used were as follows:

Treatment	Fertilizer and depth
1	Check
2	$Na_2S^*O_4$ @ 10"
3	$Na_2S^*O_4$ @ 22"
4	Na_2SO_4 @ 10" + $Na_2S^*O_4$ @ 22"
5	$Na_2S^*O_4$ @ 10" + Na_2SO_4 @ 22"

Each treated area consisted of one square yard with five-foot spacings between treatments. All treatments were randomized and replicated four times.

Depth of feeding trials were also placed on the farm field grain trials. $Na_2S{*}O_4$ was applied at 20 lb. per acre at a depth of 10 inches. The area treated consisted of one square yard with five-foot spacings between treated areas. Three square yards were treated at each location.

F. Precipitation Studies

At some of the locations in 1952 the rainfall during the growing season was collected and the amount of precipitation and the percentage sulfur determined. The rainfall was collected in two litre winchester flasks fitted with a funnel and an air vent. The funnel stem and the air vent were drawn out to a fine diameter to minimize evaporation loss. Coarse glass wool, held in place by a small stone, was placed in the bottom of the funnel to act as a filter. The flasks were set in the ground with the neck of the flask and the funnel protruding. Several stakes were driven in around each flask to serve as a marker and to prevent damage by animals.

The data from the Breton experimental plots for the years 1939 to 1949 were examined to obtain information regarding the effect of wet and dry seasons on sulfur fertilizers.

G. Soil Studies

At each location composite surface (0 to 6 inches) soil samples were taken. These were analyzed for available nutrients

by the Spurway quick method. Total sulfur and pH were also determined. Soil profiles were examined and photographed at as many trial locations as possible.

MATERIALS AND METHODS

Soil

The wooded soil zone situated to the north and west of the other soil zones occupies approximately 100 million acres. Over 30 million acres are now recognized as being generally grey wooded (35), the remainder not yet surveyed is also believed to consist mainly of grey wooded soil.

These soils have developed under humid and cool climatic conditions and low evaporation. The surface horizon consists of a semi-decomposed leaf mould layer, A_0, varying in thickness from 1 to 4 inches; a thin (sometimes absent) grey-black, brown or grey-brown A_1 horizon, 1/2 to 2 inches in depth, and a severely leached, platy, greyish A_2 horizon varying in depth from 4 to 10 inches. The B horizons are heavier textured, more compact and usually darker in color than the A horizons. The B_{C_a} or lime layer varies in depth from 30 to 60 inches.

The annual precipitation varies from 12 inches in the northern section to 22 inches in the southern. A mixed deciduous and evergreen vegetation occurs throughout the zone, peats and muskegs being frequently encountered.

The locations of the farm fields and of the experimental plots (Breton and Soils Farm) where investigations were carried

out are shown in Plate I. A brief description of the soil profiles at the plot sites is given in Table IV.

Breton Experimental Plots

These plots are located about two miles south-east of the town of Breton (70 miles south-west of Edmonton). The experimental area is divided into seven series, A to G, from east to west, and each series is composed of 26 plots from north to south. Each plot is approximately one-eleventh acre in area. Since 1930 a crop rotation using legume and cereal crops has been followed in conjunction with various fertilizer treatments. Since 1943 a five-year rotation has been used as follows: wheat, oats, barley nursing legume, hay, hay and breaking. One series, E, is cropped to continuous wheat. For further details see University of Alberta Bulletin No. 21 (35). The S^{35} experiments were confined to plots 1, 3, 4, 5, 10 and 11. The fertilizers used on these plots and their rate of application were as follows:

Plot	Fertilizer	Rate lb./ac., every 2nd year
1	Check	
3	16-20-0 + K_2SO_4	67 33
4	$(NH_4)_2SO_4$	75
5	Check	
10	16-20-0	67
11	Check	

Soils Farm Experimental Plots

These plots are located on the University Farm just south

of the city of Edmonton. The experimental area is divided into three series, A, B and C, from west to east, and each series is divided into 41 plots from north to south. Each plot is approximately one-tenth acre in area. Since 1931 a five-year rotation, the same as the one at Breton, has been followed in conjunction with various fertilizer treatments. The S^{35} experiments were confined to check plots and to plots receiving $(NH_4)_2SO_4$ (50 lb./ac.) except in 1950 when alfalfa on a plot receiving triple superphosphate (50 lb./ac.) was treated.

Fertilizers

Commercial grade fertilizers were used for the yield experiments. The trace mixture was made up from the stock of laboratory chemicals. In the experiments involving S^{35} chemically pure Na_2SO_4 was used.

The radioactive sulfur used as a tracer was obtained in 1950 from the Isotope Branch of the National Research Council, Chalk River, Ontario. In 1951 and 1952 it was obtained from the Eldorado Mining and Refining Co., Ottawa, Ontario. In 1950 and 1951 the S^{35} was received each year in two separate 20 mc. shipments of carrier-free $H_2S{*}O_4$; in 1952 a single shipment of 70 mc. was received.

In the investigations where only a single level of S^{35} was employed, the $H_2S{*}O_4$ solution was added directly to the required amount of Na_2SO_4 solution. A suitable aliquot of the resulting $Na_2S{*}O_4$ solution was retained as a laboratory standard.

The solutions of $Na_2S{*}O_4$ fertilizer for the levels experiment were prepared by first making up a stock solution of Na_2SO_4

containing 9.38 gm. per 100 ml. (9.38 gm./sq. yd. = 100 lb./ac.). Five hundred ml. of this solution were evaporated down and the 20 mc. of S^{35} added; the resulting active solution was brought up to volume and thoroughly mixed. The fertilizer solutions for the different levels were then prepared by mixing appropriate aliquots of this active solution with the required amount of the stock solution of Na_2SO_4. A portion of each of the solutions thus prepared was retained as a laboratory standard.

In the field the $Na_2S{*}O_4$ solution was dispensed from a burette into a sprinkling can, diluted to about 500 cc., then applied. In the case of the feeding depth experiments the $Na_2S{*}O_4$ solution was applied by punching, to the desired depth, 12 (1/2" diameter) evenly distributed holes in each square yard. Glass tubes were inserted in each hole and the $Na_2S{*}O_4$ dispensed down the tube from a burette. After allowing time for seepage each tube was flushed with water, removed and the hole filled with sand.

The radioactive solutions were at all times handled with approved precautions.

Sampling

Legume yield samples were weighed in the field, using a dairy scale. Two composite samples weighing two or more pounds were taken to the laboratory for moisture analysis. The determination of moisture allowed the yields to be calculated on an air dry basis.

Samples for analysis were made up in the field from the yield samples, all foreign material being excluded. Where only

analytical samples were taken, these were obtained by cutting at random an equal number of plants from each plot. The analytical samples were air dried, ground in a small hammer mill and stored in sealers pending analyses.

Legume seed samples were taken to the laboratory, passed through a Kemp sample thresher twice, cleaned using a Clipper Fanning Mill, and weighed. The resulting seed appeared to be very clean, first-grade seed.

Grain samples were threshed in a Kemp sample thresher, cleaned and weighed. Composite samples for analysis were made by grinding in a small hammer mill equal portions from each plot.

Statistical Analysis

All yield data were subjected to statistical analysis, using standard methods (22). Paired data were analyzed using the t test; the randomized block and Latin square by analysis of variance.

Determination of Nitrogen

Nitrogen was determined by the Kjeldahl-Gunning method, A.O.A.C. (3), modified by the use of selenium as a catalyst. In the distillation ammonia was recovered in 4% boric acid and titrated with N/14 sulfuric acid according to the method of Scales and Harrison (43). All nitrogen determinations were made in duplicate on composite samples. The permissable error allowed was ±0.04% N; the majority of duplicates checked considerably closer than this.

Determination of Sulfur

Oven dry samples were ashed using HNO_3 and $HClO_4$ acids

according to the method of Gieseking et al. (21). Evans and St. John (19), in testing a method similar to the one used on a number of different materials, obtained satisfactory results.

For the determination of sulfur in the non-active samples, duplicate two-gram portions were ashed and the percentage of sulfur determined turbidimetrically using a Beckman spectrophotometer. For the determination of sulfur in active samples a large portion in excess of 10 gm. was ashed (to provide thick samples for counting) and the percentage sulfur determined gravimetrically by precipitation with $BaCl_2$. The percentage sulfur obtained was checked by ashing a two-gram portion and determining the sulfur turbidimetrically.

The procedure used is given in detail in the appendix, as is a comparison between the turbidimetric and gravimetric methods. The maximum permissable error allowed for all sulfur determinations was ±0.012% S; the majority of duplicates checked considerably closer than this.

Determination of Percentage Fertilizer Sulfur

The dried precipitates from the sulfate determination were suspended in small quantities of ethyl alcohol. The suspended precipitates were transferred as quantitatively as possible to planchets by the use of special dropper tubes. In the planchet a uniform suspension of precipitate was obtained by churning the material with the dropper tube. On settling the precipitate was left evenly distributed over the bottom of the planchet. The alcohol was then evaporated under a heat lamp leaving the sample ready for counting.

Percentage fertilizer sulfur was determined according to the method of Cormack (op. cit.), using thick sample technique. Thick sample refers to a sample of such thickness that radiation from the bottom of the sample is completely absorbed by the sample. This, as determined by Cormack (op. cit.), was found to be 16 mg. per sq. cm. The relation between thick sample counting rate and specific activity of $BaS^{*}O_4$ is linear. Therefore, by using thick samples, the proportion of sulfur derived from the fertilizer may be determined directly by a comparison of the counts from plant samples with the counts of standard samples prepared from the original fertilizer solutions (Figure 1). In 1950 the amount of precipitate obtained from some of the sulfur determinations was insufficient to constitute a thick sample. In these cases it was necessary to correct for self-absorption, using a self-absorption correction curve prepared by counting various precipitated amounts of $Na_2S^{*}O_4$ of the same specific activity.

The counting equipment was the same equipment used by Cormack (op. cit.), consisting of a Tracerlab TGC-2 Geiger-Müller counter tube (resolving time 5×10^{-6} minutes) shielded by a lead castle, an N.R.C.-type pre-amplifier, a scale-of-64 scaler and a mechanical register. Regulated voltage was applied to the counter tube by means of a power supply and voltage regulator. The background count, which remained constant at approximately 30 counts per minute, was subtracted from sample counts. The performance of the counter was checked at intervals, using a uranium standard. A count on a standard sample was made at the beginning and at the end of each set of approximately five field samples. With the

exception of check plot samples, the statistical error of counting was reduced to approximately 1% by taking approximately 10,000 counts on each sample. In the cases where duplicate samples were run the maximum difference in percent fertilizer sulfur was approximately 2% with the majority of duplicates checking more closely.

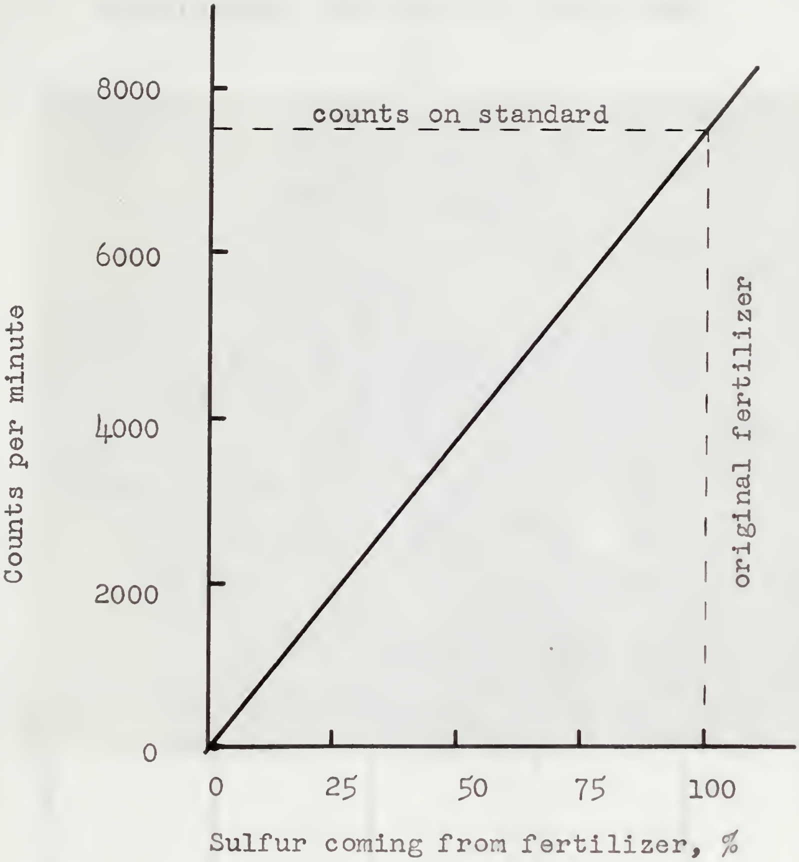
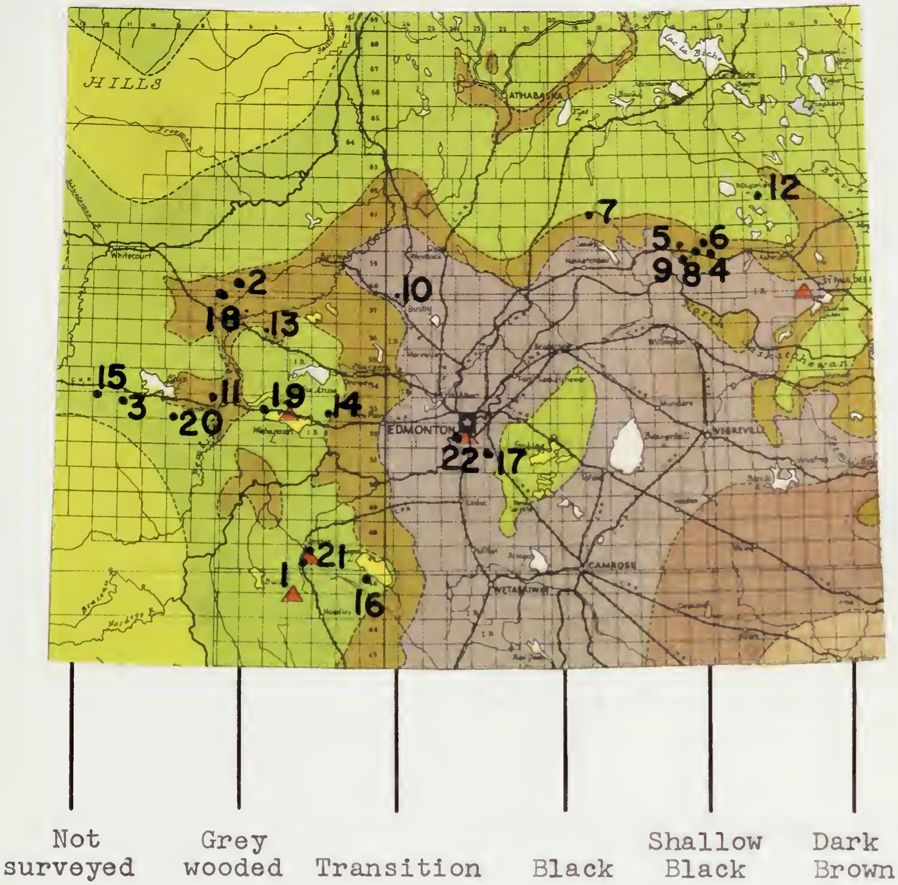


Figure 1. - Relation between thick sample counting rate and percent of sulfur coming from fertilizer, 1952.

PLATE I

EXPERIMENTAL LOCATIONS AND SOIL ZONES



Location and number of experiments -------------- •2

For key and description of profiles see Table IV.

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TABLE IV
Descriptions of soil profiles at experiment locations - 1950, '51 and '52

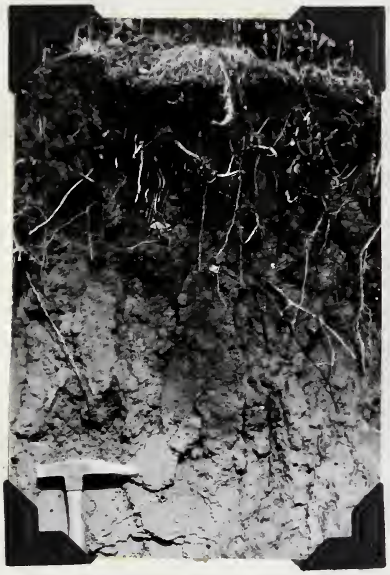
Plot site (see Plate 1)	Farmer and Address	Description of soil profile at plot site
1	Block, M. Breton	Grey wooded, residual. Paskapoo formation p.m. (parent material). Lime layer and unweathered Paskapoo sandstone at 54 in. (See Plate III A)
2	Branscombe, M. Sangudo	Grey wooded, lacustrine p.m. An exceedingly compact coarse nuciform B$_2$.
3	Burnett, D. P. Leahman	Grey wooded, glacial till p.m. Lime layer at approx. 38 in.
4	Basaraba, E. Vilna	Grey wooded, calcareous till p.m. These profiles are very similar, almost identical. All have from 15 to 18 inches of a prismatic, tending to nuciform, dark greyish-brown B$_2$. Lime layer at approx. 36 in. The Laukkanen profile appeared to be more deeply leached than the others. (See Plate II D and Plate III C.)
5	Chemery, J. Bellis	
6	Howiuk, Vilna	
7	Laukkanen, H. Hollow Lake	
8	Robertson, J. Vilna	
9	Tannas, F. Bellis	
10	Edwards, W. J. Busby	Grey wooded, calcareous till p.m. Lime layer at approx. 27 in.
11	Farrll, D.W. Evansburg	Degraded black, solonetzic, lacustrine p.m. No effervescence when treated with HCl at 30 in.
12	Gogowich, J. I. McRae	Grey wooded, glacial lacustrine p.m. Sandstone lenses appeared to be a characteristic feature of the profile. 16 to 18 in. of an exceedingly hard and compact dark-brown coarse nuciform B$_2$ with purplish staining along cleavage lines. Parent material showed evidence of salts and on analysis was found to contain 0.65 percent total salts. No effervescence when treated with HCl at 48 in. (See Plate II C.)
13	Hoff, J. I. Cherhill	Grey wooded, glacial lacustrine p.m. Iron staining indicates poor drainage. No effervescence when treated with HCl at 36 in.
14	Janke, R. Duffield	Grey wooded, glacial till p.m. No effervescence when treated with HCl at 36 in.
15	Maitland, L. D. Niton	Grey wooded, glacial till p.m. Iron staining indicates poor drainage.

TABLE IV (continued)

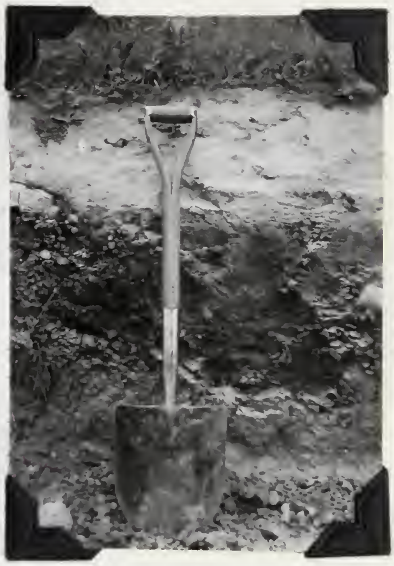
Plot site (see Plate I)	Farmer and Address	Description of soil profile at plot site
16	Mikkelson, M. P. Westrose	Grey wooded, glacial till p.m. Deeply leached. Lime layer at approx. 64 in.
17	Paul, R. R.R.2, So. Edmonton	Black, shore-line lacustrine p.m.
18	Snowden, A. Rochfort Bridge	Grey wooded, glacial lacustrine p.m. A very dense compact B_2 horizon, may be solonetzic.
19	Sveen, O. L. Seba Beach	Grey wooded, glacial till p.m.
20	Wallis, D. W. Wildwood	
21	Breton Experimental Plots Breton	Grey wooded, developed on glacial till of Paskapoo formation origin. Severely leached, having from 4 to 8 in. of light grey-brown, platy A_2. Lime layer at approx. 48 in. (See Plate II B.)
22	Soils Farm Experimental Plots Edmonton	Black, lacustrine. From 12 to 14 in. of A_0 and A_1. Lime layer at approx. 30 in. (See Plate II A.)

PLATE II

SOIL PROFILES



A. Edmonton black profile (site 22). Note the depth of A_1.



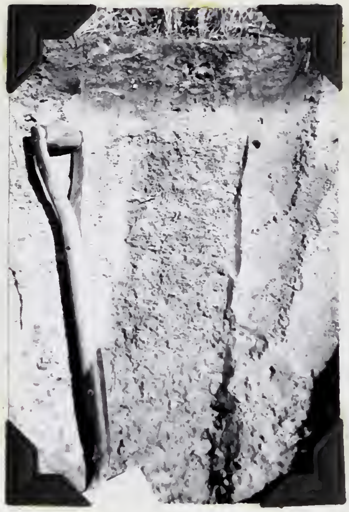
B. Breton grey wooded profile (site 21). Note the deeply leached A_2.

C. Profile at Gogowich's (site 12). Grey wooded.

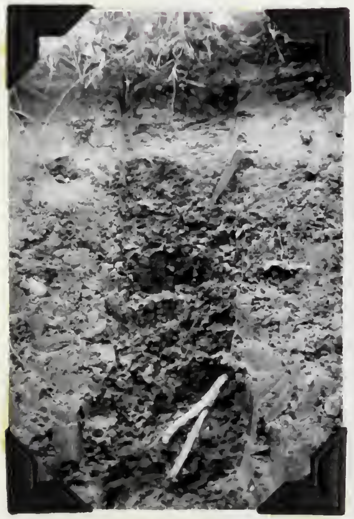
D. Profile at Laukkanen's (site 7). Grey wooded.

PLATE III

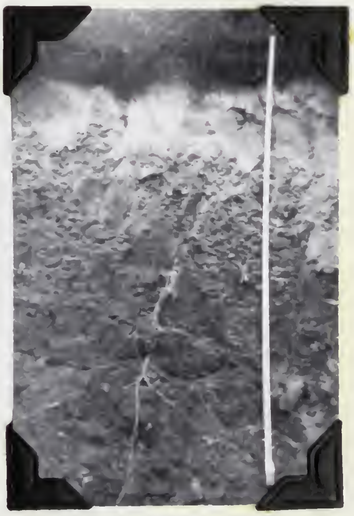
SOIL PROFILES



A. Profile at Block's (site 1). Grey wooded.



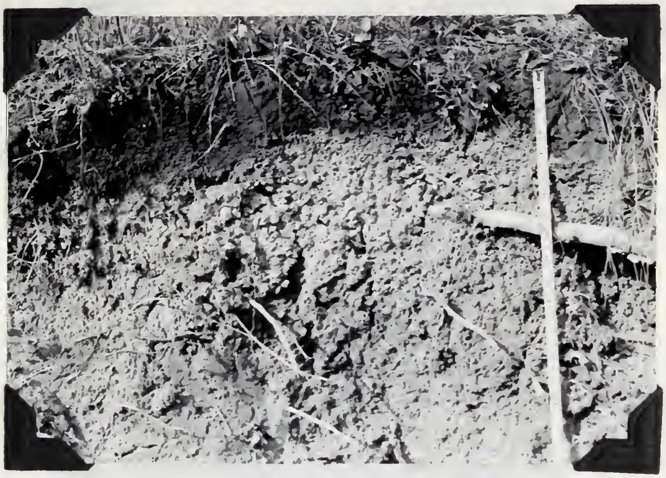
B. Profile at Janke's (site 14). Grey wooded.



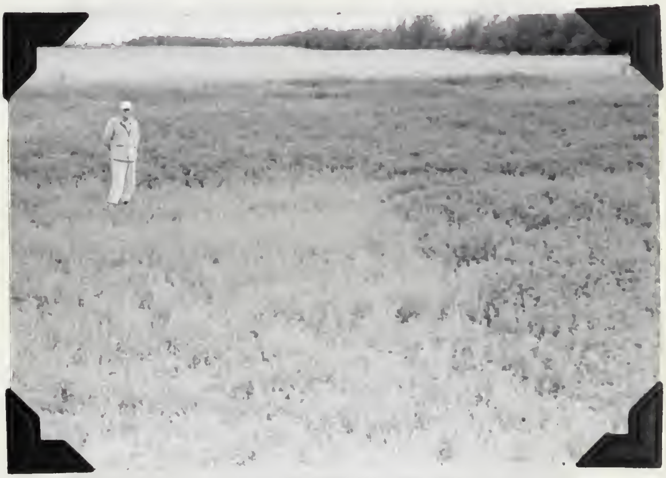
C. Profile at Howiuk's (site 6). Grey wooded.

PLATE IV

SOIL PROFILE AND PLOTS AT FARRLL'S



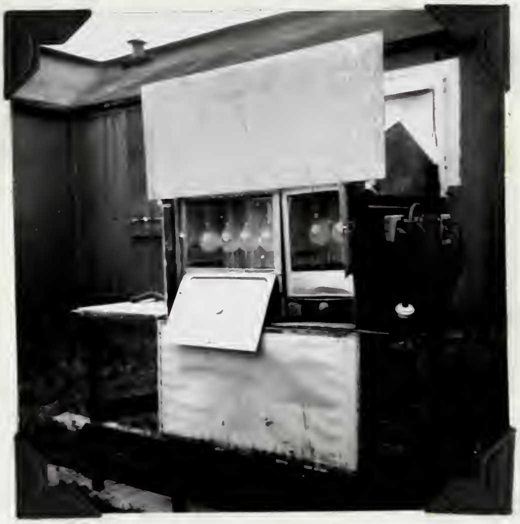
A. Profile at Farrll's (site 11). Degraded black. Note the depth of A_1 and the solonetzic B horizon.



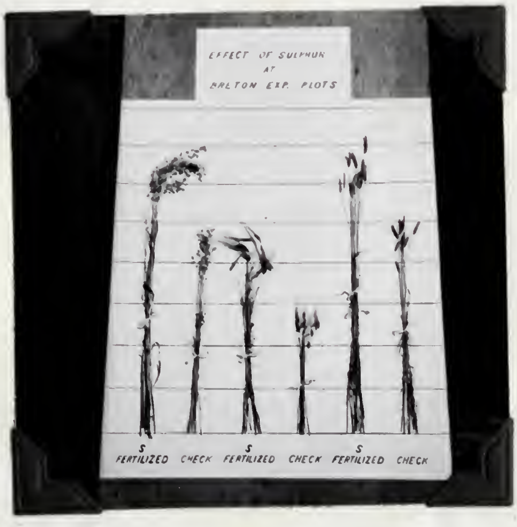
B. Sulfur fertilized plots at Farrll's. Note the pale and stunted growth of the check in the foreground.

PLATE V

ASHING OVENS AND EFFECT OF SULFUR



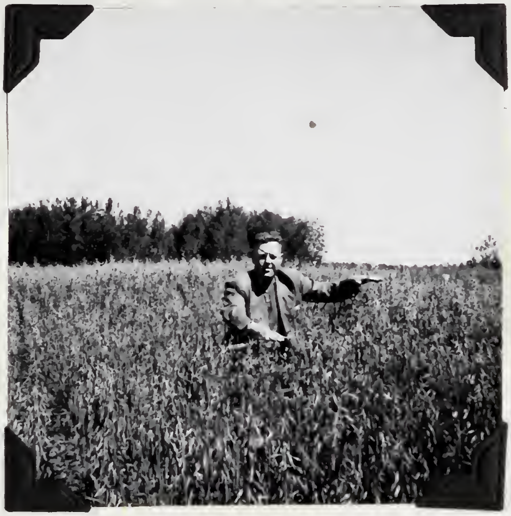
A. Ovens used in the wet ashing of active plant materials. Upright panels fold down forming roof.



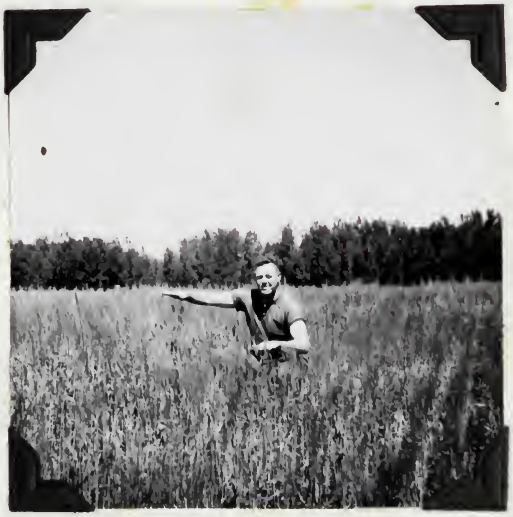
B. Effect of $Na_2S^*O_4$, supplying S @ 20 lb./ac., on grains at Breton in 1952.

PLATE VI

EFFECT OF $Na_2S^*O_4$ ON OATS AND BARLEY AT BRETON, 1952



A. Effect of $Na_2S^*O_4$, supplying S @ 20 lb./ac., on oats in rotation. Plot No. B-11.



B. Effect of $Na_2S^*O_4$, supplying S @ 20 lb./ac., on barley in rotation. Plot No. A-11.

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RESULTS AND DISCUSSION

Location, years of cultivation and the recent crop history of the various farm field fertilizer trials are given in Tables V and VI. All of the fields except those of Burnett, Mikkelson and Sveen have been under cultivation for more than 10 years, some for much longer periods.

The results of the soil analyses are presented in Table VII. The majority of the soils are slightly acidic as expected. The two black soils (Paul and Soils Farm) have a much higher percentage sulfur than any of the grey-wooded soil samples. An attempt was made to run available sulfate by the Spurway method. A very faint trace of sulfates was visible in the Hoff, Paul and Soils Farm samples.

A discussion of the results obtained from the various fertilizer experiments follows:

A. Levels Experiment

The data of the levels experiment are reported in Table VIII. None of the yield differences for the different blocks are significant; however, all levels show a depression of yield which is greatest in blocks I and II. This depression of yield approached significance in block II and in block III (grain + straw). The analyses of variance for these blocks are presented in Table IX.

TABLE V
Location, etc. for 1951 sulfur fertilization experiments

	Farmer	Plate 1 Site No.	Address	Legal Location	Years cult.	Recent Crop History	
						1949	1950
I	Legume Crops						
	Burnett, D.P.	3	Leahman	S.E.-34-53-11-5	8	Alfalfa	Alfalfa
	Maitland, L. D.	15	Niton	S.E.-30-53-12-5	15	Alfalfa	Oats + alsike
	Robertson, J.	8	Vilna	S.E.-33-59-14-4	10	Alfalfa	Alfalfa
	Tannas, F.	9	Bellis	N.E.-22-59-15-4	10	Alfalfa	Alfalfa
II	Grain Crops						
	Basaraba, E.	4	Vilna	S.W.-28-59-14-4	25	Uncropped '47-'50	Fallow
	Chemery, J.	5	Bellis	S.W.- 3-60-15-4	25	Oats	Fallow
	Wallis, D. W.	20	Wildwood	N.E.-15-53- 9-5	26	Broken from clovers	Wheat
	Sveen, O. L.	19	Seba Beach	S.W.-20-53- 3-5			Breaking

TABLE VI
Location, etc. for 1952 sulfur fertilization experiments

	Farmer	Plate 1 Site No.	Address	Legal Location	Years cult.	Recent Crop History	
						1950	1951
I	Legume Crops						
	Branscombe, M.	2	Sangudo	S.W.-19-58-6-5	12	Barley + Alf. '49 16-20 @ 35#/ac.	Alfalfa
	Edwards, W. J.	10	Busby	N.W.-3-58-27-4	14	Seeded down 1949	
	Farrll, D. W.	11	Evansburg	N.E.-31-53-7-5	15-20	Fallow	Barley + alfalfa
	Gogowich, W.	12	McRae	N.W.-1-62-12-4	20	Seeded down 1948	
	Hoff, J. I.	13	Cherhill	N.E.-16-56-5-5	40	Barley	Oats + alfalfa
	Howiuk	6	Vilna	N.E.-34-59-14-4	23	Wheat + alfalfa	Alfalfa
	Laukkanen, H.	7	Hollow Lake	S.W.-12-61-19-4	15	Fallow	Flax + alfalfa + 16-20 @ 30#/ac.
	Mikkelson, M. P.	16	Westrose	S.E.-28-46-1-5	2	Wheat + alfalfa	Alfalfa
	Snowden, A.	18	Rochfort Bridge	S.E.-16-58-7-5	15	Seeded down 1940	
II	Grain Crops						
	Block, M.	1	Breton	N.W.-13-47-4-5	20	Oats	Fallow
	Janke, R.	14	Duffield	S.E.-14-53-3-5	20	Barley '49 - 11-48 @ 35#/ac.	Barley
	Paul, R.	17	R.R.2, So.Edm.	S.W.-31-51-23-4	55	Barley	Oats

TABLE VII

Analyses of the soils where fertilizer experiments were placed

	Available nutrients p.p.m. By Spurway quick test			Total S	Total S	
	N	P	K	%	lb./ac.	pH
Farm fields						
Basaraba	5	0.75	7	0.009	180	6.9
Block	2	0.25	2	0.011	220	6.6
Branscombe	2	0.75	10	--	--	7.1
Burnett	1	0.50	11	0.015	300	6.0
Edwards	2	0.50	2	--	--	6.5
Chemery	8	0.50	12	0.013	260	6.7
Farrll	20	0.50	5	0.018	360	5.8
Gogowich	2	0.75	2	0.014	280	6.6
Hoff	8	0.75	2	0.028	560	6.5
Howiuk	10	0.75	5	0.018	360	6.2
Janke	13	1.00	2	0.019	380	6.7
Laukkanen	2	1.00	5	0.025	500	6.6
Maitland	1	0.50	10	0.013	260	6.6
Mikkelson	6	1.00	15	0.018	360	6.4
Paul	8	0.50	3	0.040	800	6.1
Snowden	20	0.75	20	--	--	6.7
Sveen	4	0.50	11	0.009	180	6.3
Tannis	0	0.50	7	0.019	380	6.9
Wallis	1	0.25	12	0.013	260	5.9
Experimental plots*						
Breton	20	0.25	13	0.010	200	6.5
Soils Farm	2	0.75	14	0.067	1340	5.9

*Only check plots analyzed.

TABLE VIII
Yield and analyses of the levels experiment conducted at Breton in 1950

Block and Treatment	Date Sampled	Gm./4 sq. ft.		S %		Fert. S %
Block I	July 21/52					
Level 1		88		--		--
" 2		82				
" 3		70				
" 4		75				
Block II	Aug. 1/52					
Level 1		141		0.13		Nil
" 2		123		0.13		38
" 3		105		0.13		42
" 4		108		0.13		43
		Grain	Straw	Grain	Straw	
Block III	Aug. 31/52					
Level 1		83	92	0.17	0.14	Nil
" 2		74	84	0.15	0.15	47
" 3		79	90	0.16	0.14	44
" 4		77	85	0.15	0.13	47

Treatments
Level 1 - Na_2SO_4 @ 100#/Ac. + 0 Mc. S^{35}/sq. yd.
" 2 - " " " + 0.04 " " " "
" 3 - " " " + 0.1 " " " "
" 4 - " " " + 0.3 " " " "

TABLE IX
Statistical analyses of blocks II and III
of the levels experiment

Source of variance	Degrees of freedom	Mean squares	F values Found	Required 5%	Required 1%
		Analysis of Variance, Block II			
Total	39	2045			
Treatments	3	2891	1.46	2.96	4.60
Replicates	9	1952			
Error	27	1983			
		Analysis of Variance, Block III (Grain + Straw)			
Total	39	1751			
Treatments	3	3129	1.96	2.96	4.60
Replicates	9	1741			
Error	27	1601			

It is to be expected that any effect of S^{35} radiation would be most apparent in blocks I and II. Initially the S^{35} would be confined to an inch or two of surface soil, becoming distributed and less concentrated throughout the upper regions of the soil profile from the percolating action of the growing season precipitation. Therefore, any effect the different levels might have would be most noticeable on the early season's growth. The levels were applied shortly after seeding at about the time the seed was germinating and it would be expected that the young developing seedlings would be particularly susceptible to radiation injury.

There are no appreciable differences between percentages of sulfur or fertilizer sulfur that could not be attributed to biological variability or to soil heterogeneity.

The data suggest that the levels of S^{35} used may be having an injurious effect; however, more experimental data would be necessary before definite conclusions could be drawn.

B. Sulfur Uptake Experiments

Breton Legumes

The 1950 data for Breton legumes are reported in Table X. No plots were placed in 1952 and the plots placed in 1951 were not sampled due to an exceedingly poor catch.

The alfalfa and clover were grown together, but segregated on harvesting and the yield of each determined. On the plots receiving $(NH_4)_2SO_4$ since 1930 the combined yield of alfalfa and clover is about the same for all treatments. On the plots receiving no $(NH_4)_2SO_4$ since 1930 there is a highly significant yield increase for both clover and alfalfa.

TABLE X
Yield and analyses of legumes on Na_2S*O_4 treated plots, Breton 1950

Crop, Plot No. and Treatment	Gm./sq. yd.	N %	S %	Fert. S %
Alfalfa				
(B-4) $(NH_4)_2SO_4$ since 1930				
Check	19.2	1.85	0.20	0.5
Na_2S*O_4 @ 30#/ac.	18.2	2.01	0.24	7
" " 100# "	14.8	1.93	0.30	10
" " 300# "	12.7	1.68	0.30	19
(B-5) No fert. since 1930				
Check	6.3	--	0.12	0.4
Na_2S*O_4 @ 100#/ac.	12.2**	2.15	0.17	68
Clover				
(B-4) $(NH_4)_2SO_4$ since 1930				
Check	51.7	2.58	0.12	0.1
Na_2S*O_4 @ 30#/ac.	60.5	2.41	0.13	11
" " 100 "	57.0	2.53	0.14	20
" " 300 "	60.0	2.45	0.13	26
(B-5) No fert. since 1930				
Check	6.5	2.48	0.12	2
Na_2S*O_4 @ 100#/ac.	17.3**	2.76	0.12	65

**Statistically significant - 1% level.

% S and % fert. S, except alfalfa check (B-5) and clover check (B-5), are the averages of single determinations on each replicate.

The $Na_2S^*O_4$ treated alfalfa plots show a definite increase in percentage sulfur. It is surprising that the clover plots do not show a similar increase.

The percentage fertilizer sulfur in the legumes is much greater for those plots receiving no fertilizer since 1930. The percent fertilizer sulfur increases as the rate of $Na_2S^*O_4$ increases.

Due to insufficient sample the nitrogen content could not be determined on the alfalfa check plot receiving no fertilizer since 1930. However, in the case of the clover receiving no fertilizer since 1930, the application of $Na_2S^*O_4$ has increased the nitrogen content considerably.

Numerous investigations (27, 31, 33, 37, 44) have shown an increase in the nitrogen content of legumes from the application of sulfur fertilizers. Miller (31) attributes this increase to a stimulating effect of the sulfur on the legume bacteria.

Breton Grain

The 1950 and 1952 data for Breton grains are reported in Tables XI and XII respectively.

In general those plots treated with $Na_2S^*O_4$, but receiving no fertilizer since 1930, show a highly significant yield increase over the check plots. In some cases, continuous wheat 1950, wheat in rotation 1950, wheat in rotation 1952, barley 1952, and oats 1952, the plots treated with $Na_2S^*O_4$ and receiving a sulfur fertilizer since 1930 show a significant increase over the check. These high yield increases are rather surprising since fertilizer results at Breton (35) from 1930 to 1949 have shown little response from the direct application of sulfur fertilizers to cereal crops.

TABLE XI
Yield and analyses of grain on Na_2S*O_4-treated plots, Breton, 1950

Crop, Plot No. and Treatment	Gm./sq. yd.		N %		S %				Fert. S %	
					Check		Na_2S*O_4			
	Check	Na_2S*O_4	Check	Na_2S*O_4	Grain	Straw	Grain	Straw	Check	Na_2S*O_4
Wheat - continuous										
(E-5) No fert. since 1930	97	124	2.43	2.47	0.14	0.09	0.13	0.15	0.8	42
(E-4) Am. S. " "	65	99*	2.63	2.65	0.15	0.17	0.14	0.19	1.1	24
Wheat - rotation										
(A-5) No fert. since 1930	38	169**	2.95	2.53	0.14	0.05	0.13	0.12	2.1	62
(A-4) Am. S. " "	142	230**	3.04	2.69	0.17	0.13	0.18	0.15	2.1	18
Barley - rotation, after clovers										
(A-5) No fert. since 1930	27	95**	2.60	2.43	0.10	0.08	0.18	0.16	0.3	61
(A-4) Am. S. " "	135	173	2.73	2.62	0.18	0.12	0.16	0.14	1.0	19
Barley - rotation, nursing clovers										
(D-5) No fert. since 1930	11	27**	--	--	0.15	0.03	0.17	0.15	1.5	37
(D-4) Am. S. " "	45-	50	--	--	0.18	0.12	0.18	0.13	1.2	26
Oats - rotation										
(F-5) No fert. since 1930	47	95**	2.46	2.03	0.14	0.04	0.18	0.16	1.6	50
(F-4) Am. S. " "	119	108	2.32	2.50	0.18	0.14	0.19	0.19	1.7	28

*Statistically significant - 5% level.

**Statistically significant - 1% level.

% fert. S and % S of grain are averages of single determinations on each replicate.

TABLE XII

Yield and analyses of grain on Na_2S*O_4-treated plots, Breton, 1952

			Grain Analyses							
	Gm./sq. yd.		N %		S %		Fert. S	Lb./Ac. S		Lb./ac.
Crop, Plot No. and Treatment	Check	Na_2S*O_4	Check	Na_2S*O_4	Check	Na_2S*O_4	%	Check	Na_2S*O_4	Fert. S
Wheat - continuous										
(E-1) No fert. since 1930	68	128*	1.91	2.02	0.11	0.14	53	0.7	1.8	1.0
(E-3) NPKS " "	173	187	1.76	1.71	0.11	0.12	28	1.9	2.2	0.6
Wheat - rotation										
(C-5) No fert. since 1930	116	194*	2.35	1.84	0.10	0.11	60	1.2	2.1	1.3
(C-3) NPKS " "	212	306*	1.87	2.06	0.11	0.14	32	2.3	4.3	1.4
Barley - rotation										
(A-11) No fert. since 1930	42	68	1.75	1.38	0.08	0.11	64	0.3	0.7	0.4
(A-10) 16-20-0 " "	78	109*	1.39	1.57	0.14	0.14	38	1.1	1.5	0.6
Oats - rotation										
(B-11) No fert. since 1930	65	95	2.33	1.73	0.13	0.14	57	0.8	1.3	0.7
(B-10) 16-20-0 " "	67	113**	2.01	1.99	0.16	0.16	40	1.1	1.8	0.7
Oats - rotation[1]										
(B-5) No fert. since 1930	65	80			0.13	0.14	34	0.8	1.1	0.4

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[1] Results refer to a barley plot fertilized in 1951 but not sampled due to hail, a decided residual effect was visible on the succeeding oat crop.

*Statistically significant - 5% level.

**Statistically significant - 1% level.

The differences in growth of the 1952 grains at Breton are shown in Plate V, B and in Plate VI, A and B.

In general, as expected, the percentage sulfur in the crops from the plots treated with $Na_2S^*O_4$ and receiving fertilizers since 1930 is higher than for check plots receiving no fertilizer since 1930. For the straws (1950) the increase in percentage sulfur ranges from 200 to 400 percent, while for the grains the increase is slight. This indicates, as would be expected, that where sulfur is a limiting factor the major portion of the sulfur is utilized by the grain at the expense of the straw.

As expected the percentage fertilizer sulfur in the crops from the plots receiving no fertilizer since 1930 is much higher than for the plots receiving sulfur fertilizers since 1930. In the case of the plots receiving no fertilizer since 1930 approximately one-half of the sulfur in the crops came from the fertilizer.

In 1952 a very noticeable residual effect was visible on the oat crop growing on the 1951 $Na_2S^*O_4$ fertilized barley plots. These plots were sampled and on analysis, as shown at the bottom of Table X, were found to contain 34% fertilizer sulfur. This is approximately two-thirds as much fertilizer sulfur as was found in similar plots fertilized in 1952. A definite yield increase is also evident.

The data for 1952 show that for both those plots fertilized and those plots unfertilized since 1930 the total amount of fertilizer sulfur taken up (lb./ac. fertilizer sulfur) was about the same.

The nitrogen data do not suggest any particular trend.

In 1950 the check samples were taken only 18 inches away from the $Na_2S^*O_4$ treated plots; consequently some of the fertilizer sulfur appeared in the check plots. However, the amount was so small that it does not invalidate any of the results, but does emphasize the need for great care in sampling small plots in fertilizer experiments. In 1952 check samples were taken five feet distant from the treated plots and were not analyzed for fertilizer sulfur.

Soils Farm, Legumes

The combined data for the years 1951 and 1952 are presented in Table XIII. The growth was sparse and poor, consequently only analytical samples were taken. The sweet clover and altaswede clover were grown together as a hay mixture and segregated for analyses.

Generally the nitrogen content of the legumes on plots receiving fertilizer since 1931 is higher than for those plots receiving no fertilizer since 1931.

The legumes on plots treated with $Na_2S^*O_4$ have a higher percentage sulfur than the legumes on check plots, and in general the legumes on plots receiving sulfur fertilizers since 1931 have a higher percentage sulfur than the legumes on plots receiving no fertilizer.

Fertilizer sulfur uptake is greatest for the legumes on plots receiving no fertilizer since 1931, but is much less than for similarly treated legume plots at Breton.

In both 1951 and 1952 check samples were taken five feet distant from treated plots and, as will be noted, there was no fertilizer sulfur present in the check samples.

TABLE XIII

Analyses of legume hay from $Na_2S^*O_4$-treated plots at Soils Farm, 1951-52

Crop, Plot No. and Treatment	N %		S %		Fert. S %	
	Check	$Na_2S^*O_4$	Check	$Na_2S^*O_4$	Check	$Na_2S^*O_4$
1951						
Alfalfa						
(C-39) No fert. since 1931	--	--	0.13	0.20	Nil	30
(C-40) T.S.P. " "	--	--	0.18	0.21	Nil	31
1952						
Sweet Clover						
(B-26) No fert. since 1931	2.59	2.52	0.21	0.26	Nil	51
(B-27) $(NH_4)_2SO_4$ " "	2.88	2.87	0.28	0.33	Nil	28
(B-32) No fert. since 1931	2.08	2.39	0.18	0.26	Nil	46
(B-33) $(NH_4)_2SO_4$ " "	1.97	2.46	0.28	0.28	Nil	40
Altaswede Clover						
(B-26) No fert. since 1931	2.85	2.91	0.16	0.19	Nil	35
(B-27) $(NH_4)_2SO_4$ " "	2.91	3.02	0.18	0.17	Nil	25
(B-32) No fert. since 1931	2.62	3.20	0.16	0.18	Nil	36
(B-33) $(NH_4)_2SO_4$ " "	3.06	2.82	0.17	0.15	Nil	31

Soils Farm, Grains

The data for 1951 and 1952 Soils Farm grains are reported in Tables XIV and XV respectively. Little reliability can be placed in the yield results, as the treated plots were in all cases near a fallowed border, consequently moisture conditions and in some cases weeds would have influenced the yield results.

The percentage sulfur of the straw (1952) on those plots receiving $(NH_4)_2SO_4$ since 1931 is considerably higher than for those plots receiving no fertilizer since 1931, and the percentage sulfur of the straw on $Na_2S^*O_4$ treated plots is considerably higher than for the check plots. The sulfur content of the straw on $Na_2S^*O_4$ treated plots receiving $(NH_4)_2SO_4$ since 1931 is approximately double the sulfur content of the check plots receiving no fertilizer since 1931.

In some cases the application of $Na_2S^*O_4$ has apparently decreased the sulfur content of the grain slightly.

Neither the application of $Na_2S^*O_4$ nor previous fertilizer history have affected the nitrogen content.

The percentage fertilizer sulfur was about the same for both years and there was little difference between plots receiving and not receiving $(NH_4)_2SO_4$ since 1931. In the case of wheat on plots not receiving fertilizer since 1931 approximately one-third of the sulfur in the crop came from the fertilizer while in the case of barley about one-half came from the fertilizer.

TABLE XIV
Yield and analyses of grain on $Na_2S^*O_4$-treated plots, Soils Farm, 1951

	Gm./sq. yd.		S %				
			Check		$Na_2S^*O_4$		Fert. S
Crop, Plot No. and Treatment	Check	$Na_2S^*O_4$	Grain	Straw	Grain	Straw	%
Wheat - rotation							
(A-7) No fert. since 1931	264	321	0.16	0.10	0.13	0.17	31
(A-8) Am. S. " "	293	396*	0.17	0.14	0.15	0.21	20
(A-13) No fert. since 1931	226	283	0.17	0.10	0.14	0.15	36
(A-14) Am. S. " "	275	296	0.17	0.18	0.15	0.21	32
Barley - rotation							
(C-26) No fert. since 1931	169	197	0.12	0.11	0.16	0.18	48
(C-27) Am. S. " "	283	259	0.15	0.20	0.17	0.23	35
(C-32) No fert. since 1931	259	191	0.16	0.11	0.17	0.20	44
(C-33) Am. S. " "	245	219	0.18	0.17	0.16	0.21	31

*Statistically significant - 5% level.

TABLE XV
Yield and analyses of grain on $Na_2S^*O_4$ treated plots, Soils Farm, 1952

Crop, Plot No. and Treatment	Gm./sq.yd.		Grain analyses							
			N %		S %		Fert. S	Lb./ac. S		Lb./ac.
	Check	$Na_2S^*O_4$	Check	$Na_2S^*O_4$	Check	$Na_2S^*O_4$	%	Check	$Na_2S^*O_4$	Fert. S
Wheat - rotation										
(B-7) No fert. since 1931	171	159	2.87	2.73	0.16	0.14	30	2.7	2.2	0.7
(B-8) $(NH_4)_2SO_4$ " "	172	152	2.82	2.75	0.17	0.15	20	2.9	2.3	0.5
(B-13) No fert. since 1931	173	155	2.73	2.74	0.16	0.14	24	2.8	2.2	0.5
(B-14) $(NH_4)_2SO_4$ " "	164	189	2.82	2.76	0.16	0.17	18	2.6	3.2	0.6
Barley - rotation										
(A-26) No fert. since 1931	139	145	1.66	1.56	0.14	0.16	41	1.9	2.3	0.9
(A-27) $(NH_4)_2SO_4$ " "	132	146	1.54	1.52	0.15	0.15	25	2.0	2.2	0.6
(A-32) No fert. since 1931	120	109	1.51	1.57	0.14	0.15	41	1.7	1.6	0.7
(A-33) $(NH_4)_2SO_4$ " "	133	143	1.56	1.63	0.15	0.15	23	2.0	2.1	0.5

Farm Fields, Legumes

The data for the 1951 legume experiments on farm fields are reported in Table XVI. Only analytical samples were taken of Maitland's first and Robertson's second cutting.

In general the yields have been increased through the application of $Na_2S^*O_4$; in Tannas' second cut this yield increase is significant for all treatments. The 20-pound rate of sulfur appears to give the best yield increase. The yields level off or decrease slightly at the 50-pound rate.

The first cutting shows a higher nitrogen and sulfur content. The nitrogen and sulfur content vary directly as the rate of application of sulfur. The low percentage in Burnett's second cut may be due to hail damage, as a severe hail storm occurred approximately two weeks prior to sampling and many of the leaves had been stripped from the stems.

The percentage fertilizer sulfur in the crop varies directly as the rate of application of $Na_2S^*O_4$ and is about the same for both first and second cut. For the higher rate of $Na_2S^*O_4$, approximately 70% of the sulfur in the plants came from the fertilizer.

Tannas check samples show a small amount of fertilizer sulfur present; this was likely due to topography, the Tannas location sloping more than the other locations.

The "translocation" samples show that at a distance of six inches an appreciable amount of fertilizer sulfur was taken up, at two feet the amount was negligible. The second cutting of "translocation" samples shows a greater uptake of fertilizer sulfur. This was likely due to the time interval between samplings, as this would allow for a greater lateral movement of fertilizer sulfur on and in the soil.

TABLE XVI
Yield and analyses of legumes on $Na_2S^{*}O_4$ treated plots of grey wooded soil, farm fields, 1951

Farm, Crop and Treatment	Tons/Ac.		N %		S %		Fert.S %	
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
Burnett - alfalfa								
Check	0.93	1.99	3.25	2.18	0.20	0.11	Nil	Nil
S @ 10#/ac.	0.86	2.93	3.27	2.08	0.23	0.10	28	21
20	1.33	3.06	3.40	2.19	0.23	0.11	38	36
50	1.30	3.06	3.28	2.15	0.28	0.14	51	42
Maitland - alsike								
Ck	--	1.40	3.35	3.06	0.15	0.16	Nil	Nil
S @ 10	--	1.95	3.63	3.05	0.21	0.18	54	44
20	--	2.03	3.62	2.92	0.21	0.17	63	59
50	--	1.77	3.69	3.07	0.22	0.22	73	73
Robertson - alfalfa								
Ck	2.13	--	3.00	2.69	0.15	0.12	Nil	Nil
S @ 10	2.46	--	3.34	2.70	0.20	0.15	52	39
20	2.56	--	3.27	3.12	0.22	0.19	65	55
50	2.29	--	3.20	3.03	0.26	0.22	71	70
Tannas - alfalfa								
Ck	0.80	0.76	2.75	2.35	0.12	0.09	0.2	0.4
S @ 10	0.92	1.25*	2.92	2.61	0.22	0.14	54	46
20	0.95	1.27*	2.98	2.61	0.24	0.18	59	59
50	0.82	1.33*	3.15	2.65	0.28	0.20	70	70
L.S.D.		0.30						
Tannas - translocation								
6" from plot with S @ 50							11	17
1' " " " " " "							0.9	7
2' " " " " " "							0.2	2

*Statistically significant - 5% level.

% S and % fert. S are averages of single determinations on each replicate.

The data for the 1952 legume experiments on farm fields are reported in Table XVII. The Branscombe field (due to a poor seed set) was cut for hay in midsummer; consequently no data are available for second cutting. In general, the results are the same as those obtained in 1951.

Most of the experiments show some response to sulfur and in some cases significant yield increases have occurred. The Laukkanen field (soil profile similar to Howiuk's) was fertilized with 16-20-0 the year previous and consequently no yield increase was evident. However, the sulfur and nitrogen content of both first and second cutting have been appreciably increased through the application of sulfur. Approximately 50% of the sulfur in the plants came from the fertilizer. The above suggests that an application of 30 lb. per acre of 16-20-0 is little more than sufficient to meet the needs of a single season's growth insofar as sulfur is concerned.

The yields were generally poor. However, the amount of sulfur removed by the better yielding plots was quite large. In the sulfur at 50 lb. plot of Mikkelson's a total of 14.3 lb. per acre of sulfur was removed by the first and second cuttings, and of this 12.4 lb. came from the fertilizer. At Branscombe's, one of the better yielding fields and one that showed no response to sulfur, approximately 8 lb. of sulfur per acre were removed by each plot in the first cutting. Therefore yields of three or more tons per acre could be expected to remove fifteen or more pounds of sulfur per acre. The application of sulfur at 20 lb. per acre would barely be sufficient to meet the needs of such a crop.

TABLE XVII
Yield and analyses of legumes on $Na_2S^*O_4$ treated plots
of grey wooded soil, farm fields, 1952.

Farm, Crop and Treatment	Tons/Ac.		Crop Analyses N %		S %		Ferb. S %		Lb./Ac. S		Lb./Ac. Ferb. S	
	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut
Edwards - alsike												
Check	0.31	0.35	3.14	2.81	0.24	0.17	0	0	1.4	1.1	0	0
S* @ 10#/Ac.	0.39	0.38	3.38	2.85	0.25	0.21	46	40	1.8	1.5	0.8	0.6
20	0.46	0.37	3.24	2.82	0.26	0.21	53	44	2.2	1.5	1.2	0.7
50	0.50	0.37	3.32	3.01	0.26	0.21	64	63	2.2	1.5	1.4	0.9
Branscombe - alfalfa												
Check	1.67		2.67		0.23		0		7.2		0	
10	1.82		2.83		0.23		26		7.9		2.1	
20	1.58		2.78		0.26		36		7.6		2.7	
50	1.67		2.77		0.25		39		7.8		3.0	
Farrll - alfalfa												
Ck	0.26	0.29	2.74	2.86	0.17	0.11	8	9	0.8	0.6	0.06	0.05
10	0.45	0.54*	2.73	2.87	0.28	0.15	62	35	2.4	1.5	1.5	0.5
20	0.59	0.77*	3.18	2.75	0.27	0.17	68	52	3.0	2.5	2.0	1.3
50	0.61*	0.91*	2.86	2.91	0.36	0.18	84	63	4.1	3.1	3.4	2.0
L.S.D.	0.35	0.20										
Gogowich - Alfalfa												
Ck	0.71	0.25	2.95	2.56	0.17	0.17	0	0	2.3	0.8	0	0
10	0.76	0.44	3.13	2.48	0.20	0.17	52	42	2.9	1.4	1.5	0.6
20	0.80	0.42	3.33	2.35	0.26	0.16	69	46	3.9	1.3	2.7	0.6
50	0.80	0.51*	3.21	2.32	0.30	0.18	71	58	4.5	1.7	3.2	0.8
L.S.D.		0.25										
Hoff - alfalfa												
Ck	0.54	0.54	3.04	2.90	0.18	0.21	0	2	1.8	2.1	0	0.04
10	0.99	0.67	3.11	2.66	0.26	0.21	54	29	4.8	2.6	2.6	0.8
20	0.99	0.80	3.30	2.87	0.33	0.23	69	50	6.1	3.5	4.2	1.8
50	0.97	0.54	3.27	2.82	0.35	0.23	73	63	6.4	2.3	4.7	1.4
Howiuk - alfalfa												
Ck	0.64	0.35	2.82	2.02	0.13	0.10	0	0	1.6	0.7	0	0
10	1.32*	0.64*	3.10	1.98	0.20	0.11	56	45	4.9	1.3	2.7	0.6
20	1.20	0.65*	3.30	2.30	0.24	0.14	64	54	5.4	1.7	3.5	0.9
50	1.18	0.86*	3.41	2.27	0.28	0.15	78	66	6.2	2.4	4.8	1.6
L.S.D.	0.67	0.19										
Laukkanen - alfalfa												
Ck	1.62	0.55	3.13	2.39	0.18	0.15	0	0	5.5	1.6	0	0
10	1.61	0.63	3.27	2.85	0.23	0.17	35	25	7.0	2.0	2.5	0.5
20	1.71	0.53	3.46	2.90	0.26	0.23	41	34	8.4	2.3	3.4	0.8
50	1.65	0.52	3.28	2.73	0.28	0.22	51	41	8.7	2.2	4.4	0.9
Mikkelson - alfalfa												
Ck	0.59	0.62	2.57	2.47	0.13	0.12	0	0	1.4	1.4	0	0
10	1.23	0.85	3.19	2.85	0.25	0.15	68	47	5.8	2.4	3.9	1.1
20	1.45*	0.90	3.05	2.98	0.33	0.17	84	60	9.0	2.9	7.6	1.7
50	1.42*	0.83	3.44	2.80	0.42	0.20	90	73	11.2	3.1	10.1	2.3
L.S.D.	0.73											

*Statistically significant - 5% level

A considerable amount of fertilizer sulfur was taken up by the alfalfa on the check plots at Farrll's. However, at Farrll's the topography was poor and it was necessary to locate the plots on a slope of approximately 5 percent. Therefore the uptake of fertilizer sulfur by the alfalfa on the check plots can be attributed largely to a lateral down-slope movement of fertilizer sulfur on and in the soil. The same, but to a lesser extent, is also true of the experiment at Hoff's where the second cutting shows 2% fertilizer sulfur in the alfalfa from the check plots.

Farm Fields, Grain

The 1951 data for grain experiments on farm fields are reported in Table XVIII. None of the yield differences are significant. Only at Wallis' has the application of sulfur appeared to definitely increase the yield.

The application of $Na_2S^*O_4$ has apparently depressed the nitrogen content slightly.

The application of $Na_2S^*O_4$ has had little effect on the sulfur content of the grain but has increased the sulfur content of the straw by approximately 100 percent.

Over 50 percent of the sulfur in the plant has come from the fertilizer sulfur. The high uptake of fertilizer sulfur and the large increase in sulfur content of the straw suggests that these soils are not well supplied with readily available sulfur.

The "translocation" samples show that little fertilizer sulfur was taken up at a distance of two feet from the fertilized plots.

TABLE XVIII
Yield and analyses of grain on Na_2S*O_4-treated plots, farm fields, 1951.

Farm, Crop and Treatment	Gm./sq.yd.		N %		S %				Fert. S
					Check		Na_2S*O_4		
	Check	Na_2S*O_4	Check	Na_2S*O_4	Grain	Straw	Grain	Straw	%
Basaraba - wheat									
Plot 1	140	150	2.00	2.09	0.10	0.05	0.13	0.10	59
" 2	172	188	1.95	2.13					53
Translocation 1'									0.4
" 2'									Nil
Chemery - oats									
Plot 1	120	106	1.46	1.42	0.12	0.05	0.11	0.12	50
" 2	112	140	1.40	1.64					56
Sveen - oats									
Plot 1	302	295	1.80	1.85	0.12	0.03	0.13	0.12	60
" 2	315	362	1.86	2.06					54
Translocation 1'									1.2
" 2'									Nil
Wallis - wheat									
Plot 1	84	108	2.25	2.12	0.11	0.04	0.11	0.10	58
" 2	83	98	2.23	2.04					58
Translocation 1'									1.3
" 2'									0.2

Translocation 1' - refers to a composite sample collected one foot away from the borders of plots 1 and 2.

The 1952 data for grain experiments on farm fields are reported in Table XIX. The results are generally similar to those of 1951.

There was considerably less fertilizer sulfur taken up in 1952. Approximately 40% of the sulfur in the plant came from fertilizer sulfur, while in 1951 over 50% came from fertilizer sulfur. The amount of sulfur removed by the grain crops (lb./ac. S) was less than the amount removed by the fertilized legume plots.

The depth of feeding experiments, in connection with these plots, show that at Janke's and Paul's (grey wooded soil) an appreciable amount of fertilizer sulfur was taken up from a depth of 10 inches, while at Paul's (black soil) a negligible amount was taken up. This indicates that when soil sulfur is present in small amounts the grain crop will feed to a considerable depth.

C. Yield Experiments with Different Sulfur Fertilizers

Legumes and Grain, 1951

The 1951 data for legumes and grain are reported in Table XX. Only yield results are reported as no analytical determinations were made on the 1951 experiments.

In the case of the Maitland experiment all fertilizers except flowers of sulfur at 10 and 20 lb. per acre gave significant yield increases. At Burnett's only Na_2SO_4 gave a significant yield increase. The Burnett results may have been affected by a severe hailstorm approximately two weeks prior to sampling.

TABLE XIX

Yield and analyses of grains on Na_2S*O_4-treated plots, farm fields, 1952

Farm, Crop and Treatment	Gm./sq. yd.		N %		S %		Fert. S	Lb.Ac. S		Lb./Ac.
	Check	Na_2S*O_4	Check	Na_2S*O_4	Check	Na_2S*O_4	%	Check	Na_2S*O_4	Fert. S
Block - oats										
Plot 1	165	242	1.48	1.33	0.13	0.13	46	2.1	3.1	1.4
" 2	171	177	1.58	1.45	0.13	0.12	45	2.2	2.1	0.9
S* @ 10"	145	187			0.10	0.12	35	1.5	2.2	0.8
Janke - barley										
Plot 1	133	209	1.87	1.94	0.13	0.14	42	1.7	2.9	1.2
" 2	182	187	1.91	1.92	0.13	0.14	41	2.4	2.6	1.1
S* @ 10"	152	157			0.13	0.12	27	2.0	1.9	0.5
Paul - barley										
Plot 1	132	139	1.66	1.63	0.13	0.14	40	1.7	1.9	0.8
" 2	145	146	1.67	1.58	0.13	0.15	37	1.9	2.2	0.8
S* @ 10"	138	142			0.13	0.15	8	1.8	2.1	0.2

S* @ 10" refers to Na_2S*O_4 applied at 20 lb./ac. at a depth of 10 inches.

TABLE XX

Yield data for 1951 sulfur experiments on grey wooded soil

Treatment	Grain crops				Legume crops	
	Basaraba wheat	Wallis wheat	Chemery oats	Sveen oats	Burnett alfalfa	Maitland alsike
	Bus./Ac.				Tons/Ac. dry hay	
Check yield	25.3	13.8	31.5	90.8	2.23	1.55
	Increase due to fertilizer					
S @ 10 lb./ac.	- 0.8	0.7	--	-23.8	-0.40	-0.13
@ 20 " "	3.2	0.2	-3.0	2.2	-0.03	0.07
@ 50 " "	2.7	1.2	-2.5	-3.8	-0.03	0.68*
$CaSO_4$	2.2	1.7	-8.5	0.2	-0.07	0.81*
$(NH_4)_2SO_4$	2.7	4.7	-3.5	-4.8	0.18	0.54*
Na_2SO_4	2.2	2.2	3.0	-3.8	0.53*	0.81*
16-20-0	4.2	0.7	4.5	4.7	0.26	0.88*
Na_2SO_4 + Trace mix.	0.2	0.7	-2.0	-0.8	0.03	0.81*
L.S.D.	--	--	--	--	0.48	0.24

*Statistically significant - 5% level.

No definite conclusions can be drawn from the grain experiments. In some cases yield increases have occurred and in others yield decreases have occurred. In three of the four experiments 16-20-0 gave a fairly substantial increase. The large decrease in yield on Sveen oats from sulfur at 10 lb. per acre was likely due to some accidental error.

Legumes, 1952

The data for the 1952 legume experiments sampled for first cutting of hay and for seed are reported in Table XXI. Sulfur fertilizers have in nearly every case increased the yield considerably and in some cases significant yield increases have occurred. Flowers of sulfur has had the least effect, indicating that the sulfur was not oxidized appreciably and therefore was unavailable to the plant.

Where yield increases have occurred the nitrogen content usually shows an increase over the check. The sulfur fertilizers have in all cases increased the sulfur content of the plants. On the better yielding plots the total sulfur in the crop was between 5 and 10 lb. per acre.

Yield of replicate samples of seed varied greatly; consequently none of the treatments showed significance. Generally the highest yielding plots gave the highest seed yield, indicating that the sulfur fertilizers had some effect on seed production. Seed yields, though they represent clean seed, are very low. A great many factors affect seed production; proper soil fertilization is undoubtedly one of them.

TABLE XXI
Yield and analyses of legumes on sulfur fertilized plots of grey wooded soil, farm fields, 1952

Farm, Crop and Treatment	First cutting				Second cutting Mature hay and seed	
	Tons/Ac.	N %	S %	S Lb./Ac.	Hay Tons/Ac.	Seed Lb./Ac.
Edwards - alsike						
Check	0.46	2.34	0.10	0.9	0.85	117
Sulfur	0.55	2.66	0.14	1.4	1.26*	118
$CaSO_4$	0.87*	2.99	0.20	3.3	2.01*	183
$(NH_4)_2SO_4$	0.90*	2.82	0.17	2.9	1.86*	203
Na_2SO_4	1.31*	3.05	0.17	4.2	2.30*	252
16-20-0	1.45*	3.12	0.18	4.9	2.30*	248
Na_2SO_4 + Trace mix.	0.96*	2.93	0.16	2.9	1.94*	162
L.S.D.	0.36				0.56	
Branscombe - alfalfa						
Ck	1.11	2.91	0.23	4.8		
S	1.47	2.92	0.33	9.1		
Gyp.	1.30	2.92	0.24	5.9		
Am. S.	1.44	2.86	0.28	7.6		
Sod. S.	1.14	2.89	0.31	6.6		
Am. P.	1.90*	3.04	0.33	11.8		
Sod. S.+ T.	1.21	2.84	0.29	6.7		
L.S.D.	0.43					
Gogowich - alfalfa						
Ck	0.65	2.81	0.13	1.6	0.79	18
S	0.78	2.81	0.14	2.5	0.82	17
Gyp.	0.86	3.21	0.33	5.3	0.99*	20
Am. S.	0.93	3.19	0.31	5.4	1.05*	26
Sod. S.	0.91	3.06	0.26	4.4	0.93	21
Am. P.	0.92	3.20	0.26	4.5	1.09*	21
Sod. S.+ T.	0.82	2.99	0.23	3.5	1.00*	20
L.S.D.					0.16	
Howiuk - alfalfa						
Ck	0.68	2.82	0.10	1.3	0.83	16
S	0.87	2.86	0.11	1.8	0.75	14
Gyp.	1.34*	3.14	0.20	5.0	1.57*	49
Am. S.	1.22*	3.11	0.21	4.8	1.66*	55
Sod. S.	0.96*	3.04	0.21	3.8	1.49*	48
Am. P.	1.36*	3.38	0.29	7.4	1.61*	25
Sod. S.+ T.	1.36*	3.25	0.18	4.6	1.54*	39
L.S.D.	0.25				0.24	
Mikkelson - alfalfa						
Ck	1.01	2.55	0.11	2.9	1.39	52
S	1.23	2.89	0.14	3.7	1.39	48
Gyp.	1.06	2.57	0.16	6.3	2.09*	94
Am. S.	1.41*	2.48	0.13	4.9	2.00*	38
Sod. S.	1.10	2.44	0.14	5.6	2.12*	47
Am. P.	1.31*	2.87	0.20	8.4	2.23*	79
Sod. S.+ T	1.06	2.33	0.13	5.0	2.06*	63
L.S.D.	0.53				0.52	
Snowden - alfalfa						
Ck	1.12	2.62	0.17	3.6		
S	0.97	2.79	0.19	3.5		
Gyp.	1.08	2.64	0.25	5.1		
Am. S.	1.00	2.70	0.20	3.8		
Sod. S.	1.04	2.61	0.21	4.1		
Am. P.	1.23	2.93	0.24	5.5		
Spd. S.+ T	1.00	2.77	0.23	4.3		

* Statistically significant - 5% level

The data for the legume experiments sampled for first and second cutting of hay in 1952 are reported in Table XXII. Farrll's second cutting shows a significant increase in yield for all sulfur fertilizers and though yields are not significant in the first cutting a definite increase is apparent. This response to sulfur fertilizers is rather surprising as the experiment was conducted on a soil commonly designated Magnolia clay and not thought to be sulfur-deficient.

Both first and second cutting of Farrll's experiment show a definite increase in nitrogen over the check for all treatments. In the other experiments those treatments showing yield increases generally show an increase in the nitrogen content as well. In Farrll's experiment the nitrogen content of the second cutting was higher than that of the first; in the other experiments the reverse occurs.

The sulfur content for all experiments, both first and second cutting, has been increased considerably by the different treatments. The combined sulfur removal of both first and second cutting approaches 10 lb. per acre for the better yielding plots.

Grains, 1952

The data of the 1952 yield experiments on grain with different sulfur fertilizers are reported in Table XXIII. In the case of the Paul experiment (black soil), Na_2SO_4 and 16-20-0 have given significant yield increases. The other fertilizers, except gypsum, gave slight increases. No satisfactory explanation can be offered for the effect of the Na_2SO_4. Appreciable increases occur in the other experiments but none are statistically significant. In

TABLE XXII
Yield and analyses of sulfur-fertilized legume experiments sampled twice in 1952. Grey wooded soil

			Hay Analyses						
	Tons/Ac.		N %		S %		Lb./Ac. S		Lb./Ac. S
Farm, Crop and Treatment	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut	2nd cut	1st cut + 2nd cut
Farrll - Alfalfa									
Check	0.55	0.38	2.23	2.76	0.12	0.12	1.2	0.9	2.1
Sulfur	0.59	0.70*	2.37	2.93	0.17	0.13	1.9	1.7	3.6
$CaSO_4$	0.80	1.43*	2.83	3.12	0.29	0.14	4.4	3.8	8.2
$(NH_4)_2SO_4$	0.74	1.36*	2.70	3.30	0.27	0.17	3.8	4.3	8.1
Na_2SO_4	0.81	1.47*	2.91	3.32	0.25	0.22	3.8	6.1	9.9
16-20-0	0.97	1.30*	2.66	3.06	0.29	0.17	5.3	4.2	9.5
Na_2SO_4 + Trace Mix.	0.75	1.34*	2.84	3.10	0.27	0.16	3.8	4.0	7.8
L.S.D.		0.28							
Hoff - Alfalfa									
Ck	1.02	0.59	3.33	2.61	0.16	0.18	3.1	2.0	5.1
S	1.02	0.62	3.08	2.68	0.17	0.20	3.3	2.3	5.6
Gyp.	0.94	0.59	3.10	2.58	0.32	0.17	5.7	1.9	7.6
Am. S.	0.85	0.53	3.21	3.06	0.26	0.24	4.2	2.4	6.6
Sod. S.	0.99	0.62	3.17	2.80	0.35	0.19	6.3	2.2	8.5
Am. P.	1.25	0.68	3.40	2.80	0.26	0.20	6.1	2.6	8.7
Sod. S. + T.	0.99	0.54	3.12	2.68	0.24	0.21	4.5	2.1	6.6
Laukkanen - Alfalfa									
Ck	1.01	1.17	3.26	1.61	0.16	0.10	3.0	2.0	5.0
S	1.23	1.29	3.36	2.08	0.19	0.15	4.4	3.6	8.0
Gyp.	1.06	1.33	3.31	1.85	0.23	0.14	4.6	3.5	8.1
Am. S.	1.41	1.55	3.23	1.90	0.25	0.14	6.6	4.1	10.7
Sod. S.	1.10	1.31	3.56	2.17	0.23	0.15	4.8	3.7	8.5
Am. P.	1.31	1.39	3.27	1.70	0.26	0.11	6.4	2.9	9.3
Sod. S. + T.	1.06	1.29	3.51	1.97	0.24	0.13	4.8	3.2	8.0

*Statistically significant - 5% level

TABLE XXIII
Yield and analyses of 1952 sulfur experiments on grain

Farm, Crop and Treatment	Bus./Ac.	N %	S %	S lb./ac.
Block - oats				
Check	52.4	1.54	0.13	2.2
Sulfur	54.0	1.53	0.17	2.9
$CaSO_4$	61.5	1.74	0.14	2.7
$(NH_4)_2SO_4$	77.2	1.53	0.13	3.2
Na_2SO_4	60.9	1.69	0.13	2.5
16-20-0	74.4	1.37	0.12	2.8
Na_2SO_4 + Trace Mix.	58.7	1.52	0.13	2.4
Janke - barley				
Check	38.4	1.88	0.11	1.9
S	42.1	1.93	0.14	2.7
Gyp.	42.4	1.93	0.15	2.9
Am. S.	39.0	2.00	0.13	2.3
Sod. S.	43.5	2.08	0.13	2.6
Am. P.	42.4	1.91	0.12	2.3
Sod. S. + T.	39.9	1.98	0.13	2.3
Paul - barley				
Ck	27.7	1.48	0.14	1.8
S	33.5	1.42	0.16	2.4
Gyp.	27.2	1.42	0.15	1.8
Am. S.	32.1	1.30	0.12	1.7
Sod. S.	34.8*	1.41	0.13	2.0
Am. P.	39.0*	1.32	0.14	2.5
Sod. S. + T.	32.1	1.37	0.13	1.9
L.S.D.	6.9			

*Statistically significant - 5% level.

Block's experiment the yields of individual samples varied greatly; consequently the large differences are not significant.

The nitrogen and sulfur content has not been appreciably affected by the sulfur fertilizers. For the better yielding plots the amount of sulfur removed by the crop was approximately three pounds per acre.

D. Fall versus Spring Fertilizer Application Experiments

The data for the fall versus spring application experiments are reported in Table XXIV. In comparing the spring and fall applications the Tannas experiment shows somewhat better results from the fall application while there is no clear difference between the two applications at Robertson's.

No conclusions can be drawn from the nitrogen data. The large variation in percent nitrogen between the check samples indicates the amount of variability, due to soil heterogeneity and biological variation, that can be expected in investigations of this kind.

The fall application of flowers of sulfur appears to have increased the sulfur content of the crop over the spring application. This would indicate that the fall application of flowers of sulfur had been more completely oxidized than the spring application and therefore was more available to the crop.

TABLE XXIV

Yield and analyses of fall versus spring fertilizer experiments, grey wooded soil, 1950-51

	Tons/Ac.		N %		S %	
Farm, Crop and Treatment	Fall	Spring	Fall	Spring	Fall	Spring
Robertson - alfalfa						
Check 1	0.77	0.89	2.57	2.36	0.09	0.10
Check 2	0.88	0.72	2.51	2.35	0.08	0.09
S @ 10#/ac.	1.58*	0.78	2.49	2.46	0.11	0.08
S @ 20 "	0.96	1.38	2.39	2.28	0.11	0.11
S @ 50 "	1.25	1.73*	2.41	2.56	0.12	0.09
$CaSO_4$	1.99*	2.34*	2.56	2.81	0.17	0.20
$(NH_4)_2SO_4$	1.75*	2.08*	2.78	2.69	0.21	0.18
Na_2SO_4	1.76*	1.91*	2.53	2.38	0.15	0.18
16-20-0	2.04*	1.75*	2.71	3.11	0.18	0.18
Na_2SO_4 + Trace Mix.	2.19*	2.28*	2.57	2.69	0.14	0.19
L.S.D.	0.76	0.73				
Tannas - alfalfa						
Ck - 1	0.90	0.82	2.61	2.30	0.09	0.09
Ck - 2	0.84	0.90	2.46	2.41	0.10	0.11
S - 10	1.36*	0.92	2.70	2.54	0.09	0.10
S - 20	0.76	0.99	2.44	2.84	0.12	0.11
S - 50	0.87	0.93	2.36	2.88	0.17	0.11
Gyp.	1.50*	0.97	2.76	3.09	0.18	0.21
Am. S.	1.10	1.09*	2.85	3.26	0.22	0.23
Sod. S.	1.34*	1.13*	2.81	3.12	0.17	0.21
Am. P.	1.33*	1.16*	2.73	2.94	0.19	0.25
Sod. S. + T.	1.55*	1.18*	2.63	2.60	0.15	0.24
L.S.D.	0.40	0.23				

*Statistically significant - 5% level.

Schalin (44), working with podzolic soils of northeastern Saskatchewan, found that where the sulfur applied was in a readily soluble form there were no differences in yield between fall and spring fertilizers. He attributed the increased yield obtained from the fall application of gypsum to its low solubility and hence to the increased solution that would be caused by fall and winter moisture. In the investigation reported here a similar conclusion could be drawn for the Tannas experiment but not for Robertson's where both fall and spring applications of gypsum gave significant yield increases.

E. Depth of Feeding Experiments

The data for the depth of feeding experiments are reported in Table XXV. As will be noted from the table, no surface application of $Na_2S^*O_4$ was applied to the check plots. This error resulted from using the word "check" on the field plan in place of "$Na_2S^*O_4$ surface application." The error was discovered too late to be rectified. The percentage sulfur and fertilizer sulfur obtained for the same rate of sulfur in the $Na_2S^*O_4$ plots in conjunction with the depth of feeding experiments have been used for purposes of comparison.

TABLE XXV
Analytical results of depth of feeding experiments
with alfalfa, grey wooded soil, 1952

Farm and Treatment	S %		Fert. S %	
	1st cut	2nd cut	1st cut	2nd cut
Howiuk				
Check	0.24	0.14	56[1]	45[1]
S* @ 10"	0.20	0.13	44	54
S* @ 22"	0.20	0.15	29	45
S @ 10" + S* @ 22"	0.20	0.16	10	16
S* @ 10" + S @ 22"	0.23	0.19	29	29
Laukkanen				
Check	0.26	0.23	35[1]	25[1]
S* @ 10"	0.25	0.20	29	25
S* @ 22"	0.21	0.17	28	27
S @ 10" + S* @ 22"	0.25	0.20	25	13
S* @ 10" + S @ 22"	0.26	0.21	32	19

S @ 20 lb./ac. applied at each depth.

% S and % fert. S of 1st cut are averages of single determinations on each replicate.

[1] No surface application of $Na_2S^*O_4$ was applied to the check plots; % fert. S and % S reported are the percentages obtained for the same rate of S in the $Na_2S^*O_4$ plots in conjunction with the above.

As was expected, the determination of percentage fertilizer sulfur on individual replicates of the first cutting showed large variations. With the technique used it was impossible to apply the sulfur without contaminating to some extent the sides of the holes. This contamination would have less effect on the second cutting due to downward leaching. Therefore the results of the second cutting are thought to be more representative of feeding depth. The use of an injection probe like the one described by Hall (23) would allow the application of sulfur to be made at the desired depth with little if any contamination of the sides of the holes.

The data reveal that the plants were able to take up considerable sulfur from the different depths. The plants took up almost as much sulfur from the 22-inch depth as from the 10-inch depth. Where non-active sulfur was applied at the 10-inch depth less sulfur was taken up from the 22-inch depth. The inclusion of non-active sulfur at the 22-inch depth caused less sulfur to be taken up at the 10-inch depth.

The various treatments have caused no appreciable change in the sulfur content.

Hunter and Kelly (25), and Weaver (51) have demonstrated that plants can absorb nutrients from considerable depths. Watenpaugh (50) was able to correlate the depth of root penetration of alfalfa with yield. The investigations referred to have all been carried out under disturbed soil conditions. Tracer technique offers an excellent opportunity of making quantitative measurements of nutrient absorption in situ.

F. Precipitation Studies

The rainfall data for some of the trial locations of 1952 are reported in Table XXVI. The rainfall collected was the amount that fell during the period from the placement of the experiment to the last harvest in the fall.

The rainfall at Breton in one case was collected under purified mineral oil to check on evaporation loss and on absorption of sulfur dioxide from the atmosphere by the collected rain water. As will be noted, the results for rainfall collected under oil are about the same as when oil was not used.

The amount of precipitation was about the same for the various experiment locations, the amount at Breton being slightly higher. As expected, the amount of sulfur brought down is highest near Edmonton. Breton has the lowest sulfur precipitation per inch of rainfall.

The data suggest that not much more than five pounds per acre of sulfur annually can be expected from precipitation in the rural areas of Alberta.

Sulfur fertilization on previously unfertilized plots of grain at Breton in 1950 showed large visible differences in growth and in nearly all cases significant yield increases were obtained. Cormack (op. cit.) obtained similar results in 1949. These results are contrary to previous results from sulfur fertilization of grains at Breton. The 1949 and 1950 growing seasons at Breton were particularly dry and this prompted the author to examine previous data at Breton to see if wet and dry seasons were affecting the response of grain to sulfur fertilizers. The data are reported

in Table XXVII. Continuous wheat was selected as it was thought that any differences would be more noticeable on a continuous grain crop. The K_2SO_4 + $(NH_4)_2SO_4$ fertilizer was included as nitrogen is also known to be brought down in precipitation.

The results indicate that in wet years sulfur fertilizers are not effective on continuous wheat, while in dry years they do have some effect. This would suggest that the increased amount of sulfur brought down in precipitation during wet years is having some effect on the crop; it does not, however, explain the apparent decreases in yield that occur in wet years from the sulfur fertilizers. Joret and Maltere (26) working in France have observed similar results. They report that the years in which sulfur was effective the total rainfall for the three spring months was between 100 and 200 mm. and that the years in which sulfur was ineffective the springs were either very dry or very wet.

TABLE XXVI
Rainfall and sulfur content at some of the experiment locations in 1952

Location	Miles from Edmonton	Pptn. in inches	S p.p.m.	S lb./ac.	Lb. of S per inch of pptn.
Breton	53	12.3	0.94	0.88	0.072
Breton (under oil)*	53	12.3	0.86	0.80	0.065
Edwards	35	11.8	1.6	1.5	0.13
Gogowich	92	8.7**	1.7	1.1	0.13
Hoff	53	11.7	1.5	1.3	0.11
Howiuk	72	10.6	1.1	0.89	0.084
Laukkanen	61	9.8	2.0	1.4	0.14
St. Albert (near Edm.)		12.9	5.0	4.89	0.38

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*Rainfall collected under purified mineral oil as a check on evaporation and on SO_2 absorption.

**Does not represent the full growing season's precipitation as collection funnel was found to be broken on removal in the fall.

TABLE XXVII
Response of continuous wheat at Breton to sulfur fertilizers as affected by wet and dry seasons

		Increase over check			
Year	Pptn.*	$CaSO_4$	Na_2SO_4	K_2SO_4	K_2SO_4 + $(NH_4)_2SO_4$
1941	7.0	-12.6	+2.4	+ 3.0	+0.4
1945	8.0	+14.0	+7.9	+ 5.6	+8.4
1939	8.3	+ 6.0	-0.3	+ 2.0	+2.0
Av. Inc. dry years		+ 2.5	+3.3	+ 3.5	+3.6
1947	11.6	-10.4	+4.8	- 3.2	-4.2
1943	11.8	- 2.6	-2.6	+ 1.6	+2.6
1942	14.9	- 7.8	-1.4	-11.1	-0.5
1944	19.8	+ 6.0	-8.6	- 3.9	+2.3
Av. Inc. wet years		- 3.7	-2.0	- 4.2	+0.2

*Precipitation refers to growing season precipitation as recorded at Breton experimental plots.

SUMMARY AND CONCLUSIONS

1. Sulfur fertilization experiments involving radioactive and non-radioactive sulfur were conducted at 22 locations. Nine of the 12 legume experiments on farm fields of grey wooded soil showed a definite response to sulfur fertilization. Yield increases as high as 300% were recorded in some cases. Of the grain experiments only those at the Breton experimental plots responded to sulfur fertilization.

2. The percentage of fertilizer sulfur in the legumes at Breton (grey wooded soil) receiving no sulfur fertilizer since 1930 was 68% for alfalfa and 65% for clover. For the legumes receiving a sulfur fertilizer since 1930 the percentage of fertilizer sulfur varied from 7% for the $Na_2S^*O_4$ at 30 lb./ac. plot, to 26% for the $Na_2S^*O_4$ at 300 lb./ac. plot.

3. The percentage of fertilizer sulfur in the grains at Breton receiving no sulfur fertilizer since 1930 varied from 37% to 64 percent. For the grains receiving a sulfur fertilizer since 1930 the percentage fertilizer sulfur varied from 18% to 40 percent.

4. The percentage fertilizer sulfur in the legumes at the Soils Farm (black soil) receiving no fertilizer since 1931 varied from 30% to 51 percent. For the legumes receiving a sulfur fertilizer since 1931 the percentage fertilizer sulfur varied from 28% to 40 percent.

5. The percentage fertilizer sulfur in the grains at the Soils Farm receiving no sulfur fertilizer since 1931 varied from 24% to 48 percent. For the grains receiving a sulfur fertilizer since 1931 the percentage fertilizer sulfur varied from 18% to 35 percent.

6. The percentage fertilizer sulfur in the farm field legumes varied from 21% to 68% for the 10 lb./ac. rate of $Na_2S^*O_4$, from 34% to 84% for the 20 lb./ac. rate of $Na_2S^*O_4$, and from 39% to 90% for the 50 lb./ac. rate of $Na_2S^*O_4$.

7. The percentage fertilizer sulfur in the farm field grains varied from 37% to 60 percent.

8. The percentage sulfur in the alfalfa ranged from a low of 0.08% for check plots to a high of 0.42% for treated plots, with an average of about 0.15% for check plots and about 0.23% for treated plots.

9. The percentage nitrogen in the legumes ranged from 1.98% for check plots to 3.44% for treated plots.

10. The nitrogen content of the legumes was generally higher for first cutting than for second cutting.

11. In most cases the application of sulfur fertilizers to grey wooded soil increased the nitrogen content of the legumes considerably.

12. Increasing the rate of application of sulfur to grey wooded soils increased the amount of fertilizer sulfur in the plants.

13. On most of the grey wooded soils investigated flowers of sulfur are apparently not sufficiently oxidized in one growing season to have much influence on that season's growth.

14. Excluding flowers of sulfur, there was no differential response of the legumes to the different sulfur fertilizers used.

15. The data presented suggest that where the sulfur content of legumes falls much below 0.15%, significant yield increases from the application of sulfur fertilizers can be expected.

16. The yield data of the levels experiment, though not significant, suggest that the levels of S^{35} employed may have had an injurious effect on barley at Breton in 1950.

17. The sulfur brought down in precipitation varied from 0.8 lb./ac. at Breton to 4.89 lb./ac. near Edmonton.

18. Data have been presented which suggest that wet and dry seasons may be having an effect on the response of grains at Breton to sulfur fertilizers.

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APPENDIX

NITRIC-PERCHLORIC ACID DIGESTION PROCEDURE

The procedure outlined below has been found satisfactory for the wet digestion of large samples of plant material.

1. Size of sample required to give a thick ppt. of $BaS*O_4$ for S^{35} counting:

   Grains and legumes - approx. 12 gm.
   Straw - " 20 gm.

2. Weigh out sample approximately. Oven dry and weigh accurately.

3. Transfer sample to 500 ml. kjeldahl, in hood with fan on, using a large funnel. Use a large camel's hair brush to brush down funnel and to brush out sample can.

4. Add approximately 7 ml. per gm. of a solution containing 1 part distilled water and 3 parts concentrated nitric acid. For convenience add 100 ml. to the grain and legume samples and 150 ml. to the straw samples, using a 1000 ml. burette.

5. Place kjeldahls in the ovens, placing a row towards the back of each oven on tall 600 ml. beakers and those in the front row on short 600 ml. beakers. (See plate V, A.)

6. Turn ovens on to medium heat, allow kjeldahls to digest with contents gently boiling, until volume has been reduced by one-half. This will take from 3 to 6 hours. Slow digestion with considerable reflux action gives best results.

7. If digestion has not proceeded smoothly under item 6, i.e., if contents have charred (contents black), it is advisable to give a second treatment using 50 ml. of the solution used in item 4 and continue the digestion as under item 6.

8. Cool and add 50 ml. of a solution made up as follows:

    Perchloric acid 70-72% - 5 parts
    Nitric acid, conc. - 2 "
    Distilled water - 3 "

    Allow to digest, boiling gently, until a clear solution results; if the volume has been reduced to 30 ml. and the samples have not yet cleared, then give a second treatment using 25 or 30 ml. of the above solution.

    The acid solution can be conveniently added to the kjeldahl flasks while in the ovens, using a 500 ml. burette. Care should be taken to wash down the necks of the kjeldahl flasks when adding the solutions.

    N.B. One should always wear a gas-mask when working around the ovens in the presence of acid fumes.

    Caution! Concentrated perchloric acid is explosive in the presence of heat and organic matter.

9. Cool and dilute the contents of each kjeldahl one-half by adding 30 to 50 ml. of distilled water.

10. Turn ovens to high and take contents to dryness.

11. Cool and add approximately 10 ml. of concentrated HCl to each kjeldahl. A 250 ml. burette is most convenient for adding the HCl treatments.

12. Turn ovens to high and take contents of kjeldahls to dryness.

13. Repeat items 11 and 12. (The HCl decomposes the chlorates and nitrates.)

14. Cool and remove kjeldahl flasks to the laboratory.

15. Add 25 ml. of 1.0 N HCl and warm gently by heating on sand bath for 10 or 20 minutes. This will dissolve all the residue except the silica.

16.- Filter through a qualitative filter paper, washing the kjeldahl flask well.

17. Make filtrate up to approximately 300 ml., heat to near boiling and precipitate the sulfur by adding approximately 35 ml. of a 2% solution of $BaCl_2$.

PREPARATION OF PRECIPITATED BaS^*O_4 FOR COUNTING

1. Allow the solution containing the precipitated BaS^*O_4 to stand overnight or longer.

2. Transfer, by aspiration, the supernatant liquid into a 500 ml. volumetric flask.

3. Wash the precipitate into a tared 40 ml. conical centrifuge tube.

4. Centrifuge for approx. 3 min. at 1000 r.p.m.

5. Transfer, by aspiration, the supernatant liquid into the volumetric flask.

6. Wash the precipitate with approx. 30 ml. of distilled water.

7. Centrifuge as in item 4.

8. Draw off supernatant liquid as in item 5.

9. Wash once more with distilled water as under items 6, 7 and 8.

10. Wash the precipitate with approx. 20 ml. of 95% ethanol.

11. Centrifuge as in item 4.

12. Draw off, by aspiration, the supernatant ethanol and save for reclamation.

13. Dry precipitate, in centrifuge tube, overnight at 105°C.-110°C.

14. Weigh centrifuge tube plus precipitate (for calculation of % S).

15. With a dropper tube add approx. 1 ml. of 95% ethanol to the centrifuge tube.

16. With the dropper tube work the precipitate of $BaS{*}O_4$ into suspension.

17. By means of the dropper tube transfer the slurry of $BaS{*}O_4$ to planchett. A second smaller portion of ethanol can be used to make the transfer more quantitative.

18. With the dropper tube churn the precipitate of $BaS{*}O_4$ into a uniform suspension and allow to settle.

19. Evaporate the excess ethanol off using a heat lamp.

After the ethanol has all evaporated, the precipitate of $BaS{*}O_4$ will usually present a smooth, even surface, otherwise, the process of churning, etc. should be repeated until a reasonably smooth surface is obtained. The samples can be conveniently stored in petri dishes until counted.

The remaining solution of the ashed sample can be made up to volume in the volumetric flask and other elements determined if desired.

TURBIDIMETRIC SULFUR DETERMINATION

The procedure used was that developed by F. W. Schroer* and C. F. Bentley of the Soils Department, University of Alberta, and is suitable for solutions with sulfate concentrations of 10 to 100 p.p.m. For plant materials one gram made up to 100 ml. will fall near the midpoint of the above range.

A Beckman model D.U. Quartz Spectrophotometer was used to measure turbidity. A standard curve was prepared using C.P. Na_2SO_4 solutions 1/10 N with HCl. The sulfate was precipitated using $BaCl_2$ crystals of 20 to 30 mesh, measured with a scoop which gave approximately 0.045 gm. per scoopful. The procedure and settings are as follows:

Spectrophotometer settings

Wavelength - 500 mu.

Slit-width - 0.15 mm.

Selector switch at 1.0 position

Sensitivity about 2 turns from clockwise limit

Red phototube.

Solutions

Blank

Approx. 3 ml. of distilled H_2O plus one drop of 5 N HCl (= about 1/10 N) and one scoop of $BaCl_2$ crystals.

Unknowns

1/10 N with HCl and in the ranges already indicated.

Transfer approximately 3 ml. to the cell; add a scoop of

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*Dominion Soil Survey.

$BaCl_2$ crystals and shake with a rocking motion (to avoid air bubbles) until dissolved (about 45 seconds); allow to sit 3 minutes before reading.

Duplicate readings were taken on each sample and p.p.m. of sulfate determined from the standard curve.

Cells should not be used more than three times without being cleaned (soap and soft brush) as a slight clouding due to deposited $BaSO_4$ develops and will cause lowered readings.

Calculation

$$\% S = \frac{\text{p.p.m. } SO_4}{10^6} \times \text{dilution factor} \times \frac{S}{SO_4} \times 100$$

Samples for turbidimetric sulfur determination were ashed inside of a fume cabinet using a hot plate and 250 ml. electrolytic beakers. A 2 gm. sample was ashed and proportionately smaller quantities of the reagents were used.

A comparison of the turbidimetric and the gravimetric methods of sulfur analyses and of wet ashing with Na_2CO_3 fusion is given in Table XXVIII. The turbidimetric and gravimetric methods agree very closely. There is a tendency for the turbidimetric method to give slightly lower results. The Na_2CO_3 fusion gave much lower results; this in all probability is due to volatilization of some of the sulfur during the fusion process.

TABLE XXVIII

Comparison of gravimetric and turbidimetric methods of sulfur analyses and of wet ashing with Na_2CO_3 fusion on composite samples of crop material

	Wheat grain		Alfalfa			Oat Straw		
			Wet Ashing			Wet Ashing		
	Wet Ashing	Na_2CO_3 Fusion	Gravimetric	Turbidimetric	Na_2CO_3 Fusion	Gravimetric	Turbidimetric	Na_2CO_3 Fusion
	S %	S %	S %	S %	S %	S %	S %	S %
	0.146	0.093	0.294	0.294	0.258	0.128	0.128	0.107
	0.144	0.096	0.294	0.289	0.236	0.130	0.133	0.106
	0.141	0.087	0.294	0.289	0.227	0.127	0.126	0.098
	0.140		0.294	0.277		0.127	0.126	
	0.144		0.296	0.289		0.128	0.119	
	0.137		0.293	0.288		0.128	0.122	
	0.119*		0.291	0.295		0.128	0.125	
	0.108*		0.294	0.298		0.130	0.126	
	0.091*		0.302	0.302		0.132	0.127	
	0.078*		0.304	0.299		0.131	0.134	
Mean	0.142	0.092	0.296	0.292	0.240	0.129	0.127	0.104
s.d.	0.0024		0.0041	0.0072		0.0017	0.0045	

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*These samples inadvertently went to dryness on digestion with nitric acid and were severely charred. They are not included in the calculation of average or standard deviation.

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